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**MULTIMODAL AND MULTIDIMENSIONAL GEODATA
INTERACTION AND VISUALIZATION**

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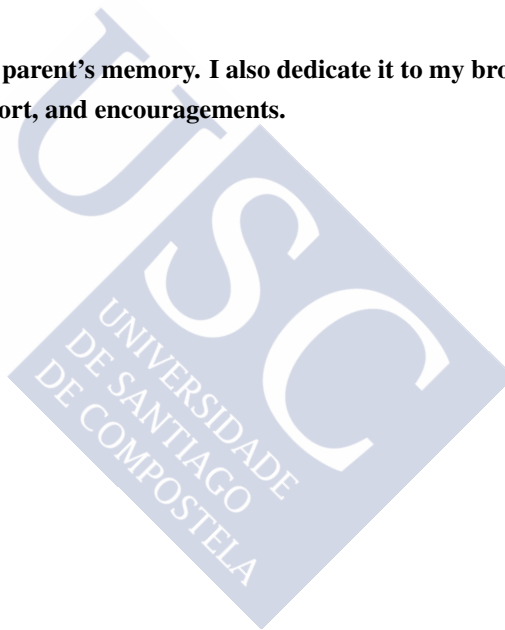
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DEDICATION

I dedicate this thesis to my parent's memory. I also dedicate it to my brother and sisters for their endless love, support, and encouragements.





Storytelling is ultimately a creative act of pattern recognition. Through characters, plot and setting, a writer creates places where previously invisible truths become visible. Or the storyteller posits a series of dots that the reader can connect.

Douglas Coupland

Creativity and insight almost always involve an experience of acute pattern recognition: the eureka moment in which we perceive the interconnection between disparate concepts or ideas to reveal something new.

Jason Silva



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Resumo

Presentamos nesta tese un traballo de investigación para a visualización efectiva de diferentes tipos de datos xeográficos. A visualización lévase a cabo co uso dun SIX (como GoogleEarth), e implementouse un caso de estudo:

Visualización de datos arqueolóxicos procedentes de escavacións dun castelo situado en Galicia, O Castelo da Rocha Forte, que permitiron a visualización e análise de información arqueolóxica xeorreferenciada. Esta implementación denominouse Sistema de Contornas Xeográficas Virtuais (ArVS) e resultou ser moi eficiente, xa que pode manexar diferentes tipos de datos de 1, 2 ou 3 dimensións, tales como texto, artefactos e a reconstrución 3D de elementos históricos. Ademais, o sistema mostrouse útil xa que proporciona acceso á base de datos da escavación en tempo real e actualiza eficientemente a visualización da mesma.

A visualización no sistema implica o uso de novos paradigmas de visualización que poden tratar datos e representar obxectos nunha mesma posición xeográfica ou moi similar. O sistema proporciona visualización multicapa mellorada que evita a superposición e unha interface de diálogo para filtrar os datos a visualizar, que reduce o tempo para obter a información da base de datos, o que se reflicte na mellora do rendemento do sistema suxerido, ademais, da capacidade de axustar a precisión dos datos para encaixar cun Nivel de Detalle (LOD) específico. Así mesmo, o sistema integra o uso de novas técnicas de interacción home-máquina (HCI) que permiten tratar mapas e obxectos mediante unha interacción para a navegación máis natural: navegación usando xestos e control por voz. Isto permítelle ao sistema axudar aos usuarios finais e aos arqueólogos para explorar os datos e a análise das escavacións de forma segura e práctica con novos métodos de visualización e navegación. O noso sistema escala facilmente e o acceso a outras bases de datos diferente á usada no caso de uso é sinxelo.

O uso de ArVS permitirá visualizar de forma online, sobre un visualizador de SIX dunha forma natural e intuitiva, datos arqueolóxicos remotos, axudando a protexer o patrimonio en todos aqueles países que sofren da destrución sistemática do seu patrimonio arqueolóxico debido ao terrorismo e as guerras.

Palabras chave: Interacción Home-Máquina, Sistemas de Información Xeográfica, Interacción Multimodal, Reconeimento Xestual, Contornas Xeográficas Virtuais (EEV), Visualización de Datos Arqueolóxicos, Visualización de Información.



Resumen

Presentamos en esta tesis un trabajo de investigación para la visualización efectiva de diferentes tipos de Geodatos. La visualización se lleva a cabo con el uso de un GIS (como GoogleEarth), y se ha implementado un caso de estudio.

Visualización de datos arqueológicos procedentes de excavaciones de un castillo situado en Galicia, O Castelo de A Rocha Forte, que han permitido la visualización y análisis de información arqueológica georreferenciada. Esta implementación se ha denominado Sistema de Entornos Geográficos Virtuales (ArVS) y resultó ser muy eficiente, ya que puede manejar diferentes tipos de datos de 1, 2 o 3 dimensiones, tales como texto, artefactos y la reconstrucción 3D de elementos históricos. Además, el sistema se ha mostrado útil ya que proporciona acceso a la base de datos de la excavación en tiempo real y actualiza eficientemente la visualización de la misma.

La visualización en el sistema implica el uso de nuevos paradigmas de visualización que pueden tratar datos y representar objetos en una misma posición geográfica o muy similar. El sistema proporciona visualización multicapa mejorada que evita la superposición y una interfaz de diálogo para filtrar los datos a visualizar, que reduce el tiempo para obtener la información de la base de datos, lo que se refleja en la mejora del rendimiento del sistema sugerido, además, la capacidad de ajustar la precisión de los datos para encajar con un Nivel de Detalle (LOD) específico. Asimismo, el sistema integra el uso de nuevas técnicas de interacción hombre-máquina (HCI) que permiten tratar mapas y objetos mediante una interacción para la navegación más natural; navegación usando gestos y control por voz. Esto permite al sistema ayudar a los usuarios finales y a los arqueólogos a explorar los datos y el análisis de las excavaciones de forma segura y práctica con nuevos métodos de visualización y navegación. Nuestro sistema es fácilmente escalable y el acceso a otras bases de datos diferente a la usada en el caso de uso es sencillo.

El uso de ArVS permitirá visualizar de forma online, sobre un visualizador de GIS, de una forma natural e intuitiva, datos arqueológicos remotos, ayudando a proteger el patrimonio en todos aquellos países que sufren de la destrucción sistemática de su patrimonio arqueológico debido al terrorismo y las guerras.

Palabras clave:

Interacción Hombre-Máquina, Sistemas de Información Geográfica, Interacción Multimodal, Reconocimiento Gestual, Entornos Geográficos Virtuales (EEV), Visualización de Datos Arqueológicos, Visualización de Información.



Summary

We present in this thesis a research work for the effective visualization of different types of Geodata. The visualization is carried out with the use of a GIS (such as GoogleEarth), and a case study has been implemented.

Visualization of archaeological data from excavations of a castle located in Galicia, O Castelo de A Rocha Forte, which have allowed the visualization and analysis of georeferenced archaeological information. This implementation has been called Virtual Geographic Environment System (ArVS) and proved to be very efficient, as it can handle different types of 1, 2 or 3 dimensional data, such as text, artefacts and 3D reconstruction of historical elements. In addition, the system has proved useful as it provides access to the excavation database in real time and efficiently updates the visualization of the excavation.

Visualization in the system involves the use of new visualization paradigms that could treat data and represent objects in the same or very similar geographic position. The system provides enhanced multilayer visualization that avoids overlapping and a dialogue interface to filter the data to be visualized, which reduces the time to obtain the information from the database, which is reflected in the improved performance of the suggested system, and the ability to adjust the precision of the data to fit a specific Level of Detail (LOD). In addition, the system integrates the use of new Human-Machine Interaction (HCI) techniques that allow maps and objects to be treated through interaction for more natural navigation; navigation using gestures and voice control. This allows the system to help end users and archaeologists to explore excavation data and analysis in a safe and practical way with new visualization and navigation methods. Our system scales easily and can access to other databases different than the one used in the case of use, in a simple way.

The use of ArVS will allow to visualize online, on a GIS viewer, in a natural and intuitive way, remote archaeological data, helping to protect the heritage in all those countries that suffer from the systematic destruction of their archaeological heritage due to terrorism and wars.

Keywords:

Human Computer Interaction, Geographic Information Systems, Multimodal Interaction, Gestural Recognition, Virtual Geographic Environments (VGE), Archaeological Data Visualization, Information Visualization.





Resumen extendido

En nuestro ámbito de trabajo un mapa es considerado como una representación simbólica que enfatiza las relaciones entre los elementos del territorio. En los últimos 30 años, la importancia de los mapas, como medio de comunicación de la información se ha visto incrementada por su uso en diferentes ámbitos de aplicación tales como; cartografía, ciencias sociales, geografía, historia o medicina. En este sentido, a fin de facilitar el análisis de estos, se han desarrollado un conjunto de herramientas denominadas genéricamente Sistemas de Información Geográfico (GIS) que permiten la visualización y el análisis computarizado de estos datos denominados genéricamente datos geoespaciales, facilitando enormemente la labor del usuario. Los sistemas GIS han provocado cambios significativos en los paradigmas del trabajo cartográfico desarrollando nuevos modos de comunicar información espacial. La aparición de los GIS, las redes de comunicación, los GPS y los modelos digitales del terreno precisos han permitido la estandarización de servicios que proveen información cartográfica e información georreferenciada precisa y masiva, desarrollándose infraestructuras de datos espaciales, SDI, que permiten a un usuario cualquiera acceder a la visualización de datos de muy diversa naturaleza sobre un sistema cartográfico georreferenciado. Es el caso de GoogleEarth, o GoogleMaps.

Los datos geoespaciales se clasifican en tres grandes grupos; datos gráficos, vectoriales y ráster. Los datos gráficos se pueden mostrar en forma de red (carreteras), mientras que la categoría vectorial de datos puede aparecer como áreas, líneas o puntos. La categoría de datos ráster se asocia a imágenes de la superficie terrestre, que generalmente se obtienen mediante sensores de satélite, mediante aviones, o más recientemente, mediante drones. En la última década, la cantidad de datos geoespaciales ha aumentado drásticamente, debido al uso generalizado de dispositivos informáticos y sensores. Esto ha llevado a la aparición del concepto

denominado Geospatial Big Data, que se define como colecciones de datos geoespaciales que superan la capacidad de los sistemas informáticos convencionales.

En la cartografía digital, los datos son tratados computacionalmente permitiendo fusionar en ellos múltiples fuentes lo que permite un análisis conjunto de los mismos. Los objetos de un mapa digital están caracterizados por un conjunto de metadatos que permite identificarlos, analizarlos y son el elemento clave para unificarlos en una única entidad. No obstante, actualmente la interacción con los sistemas GIS se realiza mediante ratón y teclado, que permiten realizar tareas tales como editar, analizar, almacenar y datos los datos que en muchos casos resulta ser una labor compleja.

Según Donalk [6], el concepto de visualización se define como el puente central que conecta el contenido de los datos cuantitativos con la percepción humana. Los contextos científicos enfatizan que el proceso de visualización tiene como objetivo proporcionar a los científicos herramientas óptimas, que ayudan a descubrir las relaciones y los patrones ocultos dentro de series de datos, así como a crear representaciones visuales con propiedades significativas. Por lo tanto, se distingue la visualización por su capacidad para establecer una interfaz de interacción entre datos digitales y los humanos mejorando su percepción. El descubrimiento de patrones ocultos y correlaciones no identificadas se considera como el principal reto al que se enfrenta a la visualización de grandes volúmenes de datos. Por otro lado, la representación visual de estas grandes cantidades de información en tiempo real no es una tarea fácil debido a lo heterogéneo de los datos a representar presentando diferentes tipologías, y dimensiones. Un estudio reciente [10] comparó y evaluó el rendimiento de la visualización bidimensional, la visualización tridimensional y un híbrido entre ellos. Estos casos fueron evaluados basándose en el volumen de tareas de interés y experimentos de estimación de posición relativa.

Los resultados obtenidos de estos experimentos[10] indican que la combinación de dos dimensiones con tres dimensiones en un geo espacio permite mejorar la representación. Además, permite una mejor navegación y brindan una mayor confianza en el análisis de los mimos por parte del usuario.

A fin de aunar todas estas posibilidades en los últimos años se han desarrollado una serie de visualizadores que permiten el acceso información geográfica a múltiples usuarios. Van Asperen et al. y Patterson en [16,17], verifican el rendimiento de las tres principales aplicaciones GIS (World Wind de la NASA, MSN Virtual Earth 3D y Google Earth) en la distribución de geoinformación su acceso a datos geoespaciales en estándares abiertos tales

como los establecidos por el Consorcio Geoespacial Abierto (OGC). De los tres antes presentados el Google Earth demostró ser técnicamente superior a otras aplicaciones GIS. Por lo que ha sido utilizado en múltiples aplicaciones para todo tipo de usuarios. Esto ha desembocado en la necesidad de definir interfaces que simplifiquen la labor del usuario en función de sus conocimientos sobre sistema.

Por otra parte, el concepto de entorno virtual (VE) como un ambiente generado por computador que rodea totalmente al usuario, intenta definir un nuevo paradigma de interacción entre el hombre y el computador. En estos entornos el usuario se encuentra dentro de un mundo digital que puede explorar interactuando con los objetos del mismo de forma natural desarrollando una interacción multimodal con el sistema. Por tanto, para el desarrollo de este tipo de entornos es necesario el uso de nuevos dispositivos denominados genéricamente *somatosensory devices*. Estos dispositivos permiten la interacción con el entorno mediante el uso de la voz, movimiento de las manos o de los brazos, siendo capaces de reconocer movimientos y gestos de los usuarios permitiendo una interacción más natural.

En los últimos años con la aparición de herramientas computacionales más potentes permiten aunar las dos ideas antes planteadas GIS y VE en único concepto, los denominados Virtual Geographic Environments (VGE). Hoy los VGE están expandiendo rápidamente los dominios de aplicación para la visualización de información geográfica y el análisis de los datos, utilizando entornos de trabajos diseñados para ayudar a la inferencia espacio-temporal y a la toma de decisiones. Sin embargo, hay varios desafíos que enfrentan los usuarios en el dominio de VGE que desde nuestro punto de vista pueden ser resumidos en:

1. El acceso remoto a bases de datos desde motores gráficos estandarizados, así como la representación de la información geo-espacial.
2. Permitir la representación de diferentes tipos de datos procedentes de diferentes fuentes de información.
3. Proporcionar a los usuarios varias opciones de nuevas técnicas de interacción.
4. Definir paradigmas de representación que permitan simplificar la visualización cuando los elementos coinciden en la misma posición (proporcionando al usuario final una vista clara).
5. Desarrollar modos de visualización que permitan visualizar en función de la distancia a los elementos aquellos que son visibles y aquellos que no (LOD).

6. Representación de información multidimensional en la misma escena.
7. Desarrollo de interfaces multimodales para interaccionar con las diferentes representaciones.
8. Soporta palabras simples y cortas para mejorar la precisión del reconocimiento de voz y el proceso de control.

Esta tesis doctoral se centra en el diseño e implementación de una aplicación en el ámbito de los Sistemas de Información Geográfica, desarrollando nuevos modos de visualización de datos e interacción con los mismos. La herramienta desarrollada utiliza como motor de visualización el Google Earth, sobre el cual representamos una gran cantidad de datos arqueológicos lo que presenta una serie de retos desde el punto de vista de la representación, interacción y eficiencia, conformando una única herramienta que denominamos (ArVS). La base de datos alojada en el Centro de supercomputación de Galicia (CESGA) procede de la excavación del castillo de A Rocha Forte y presenta los problemas de visualización atribuibles a este tipo de excavaciones, principalmente superposición de información espacio-temporal en un mismo punto.

Nuestro sistema posibilita la inclusión de varias fuentes de información de 1, 2 ó 3 dimensiones y utiliza nuevos modelos de visualización que permiten datos y objetos en una posición similar, mediante una estructura multicapa sin causar una superposición de datos. Esto mejora y reduce el tiempo para obtener la información de la base de datos, lo que se refleja en la mejora del rendimiento general del sistema.

En este sentido, el objetivo principal de este trabajo es determinar cómo interactuar y visualizar geo-datos, así como proteger y preservar los datos arqueológicos y patrimoniales en todos los países que sufren la destrucción de la arqueología debido al terrorismo y a las guerras. Esto permite ayudar a los usuarios finales y a los arqueólogos a explorar y analizar los datos de las excavaciones de forma segura y práctica con nuevos métodos de visualización y navegación. La escalabilidad del sistema, así como su fácil implementación hace que su aplicación a otros yacimientos arqueológicos sea sencilla.

Otro de los elementos fundamentales que se ha considerado es el modo de interacción entre la aplicación y el usuario. Como fue comentado con anterioridad los métodos tradicionales de interacción con sistemas GIS limitan la usabilidad y ralentizan la interacción que se produce cuando se utilizan dispositivos convencionales como el ratón y el teclado. En este

sentido se han considerado otros modos de interacción tales como la voz humana y los gestos de las manos que pueden crear acciones más cercanas al usuario.

La parte de visualización utiliza técnicas de interacción multimodal que puede aplicarse a otro tipo de sistemas. Esta herramienta incluye cinco técnicas para la interacción multidimensional de datos geográficos basada en gestos y reconocimiento de voz; proporcionando un método de entrada flexible que permite a usuarios no expertos desarrollar un número significativo de tareas lo que mejora la toma de decisiones y la prevención de errores.

El sistema se ha aplicado en el Centro Singular de Investigación en Tecnologías de la Información (CITIUS) de la Universidad de Santiago de Compostela (España) y en el Real Centro Geográfico Jordano (Jordania), lo que nos ha permitido verificar su rendimiento en las diferentes técnicas implicadas en esta memoria. La usabilidad del sistema ArVS ha sido validada con dos tipos de usuarios, estándar y expertos, que han tenido la posibilidad de realizar operaciones básicas o análisis avanzados de los datos almacenados. Tras este período de uso, se les ha pasado una encuesta que ha evaluado los dos aspectos del trabajo desarrollado. Los paradigmas presentados de visualización y las técnicas de interacción multimodal implementadas. Los resultados de los test han sido satisfactorios en ambos casos, alcanzando una satisfacción media del usuario de más del 85%.

En resumen, en este trabajo se propone el desarrollo e implementación de un Sistema de Visualización de Datos Científicos (SdVS), dentro de un marco general de trabajo, aplicando nuevos paradigmas de visualización de datos científicos y técnicas de interacción hombre-máquina intentado responder cinco preguntas fundamentales sobre los sistemas arqueológicos de SIG:

1. Cómo adaptar la resolución de los datos para que se ajusten a un Nivel de Detalle específico de la visualización.
2. Cómo integrar representaciones bidimensionales y tridimensionales en las mismas escenas.
3. Cómo representar multitud de objetos en las mismas coordenadas sin superposición.
4. Cómo aplicar los nuevos métodos de visualización.
5. Cómo crear y aplicar nuevas técnicas no tradicionales de interacción persona-computadora.

Finalmente, de acuerdo con lo anterior, esta tesis trata de considerar cómo hacer que los sistemas GIS sean más comprensibles y accesibles al público en general con la integración entre visualización e interacción, facilitando así la capacidad de comprensión de la información arqueológica por parte de usuarios y expertos.

Creemos que los diferentes objetivos de esta investigación se han logrado con éxito destacando las siguientes conclusiones:

1. Se ha diseñado, implementado y probado una arquitectura distribuida y escalable que permite operar con dispositivos de bajo coste y software abierto en sistemas de interacción GIS.
2. Se han implementado y probado cinco formas diferentes de técnicas de interacción.
3. Se han desarrollado e implementado seis nuevos paradigmas de visualización que permiten a los usuarios visualizar e interactuar con sus datos y obtener conocimiento de una manera atractiva y de una manera diferente.

La interacción multimodal desarrollada en el sistema ArVS tiene muchos usos potenciales en Aplicaciones GIS, porque es una forma natural de comunicarse con el ordenador. Este tipo de interacción favorece la experiencia del usuario en este campo. En particular, la combinación de gestos y voz ha demostrado que se complementan entre sí para definir acciones de navegación en entornos visuales 2D y 3D.

Hemos desarrollado un nuevo componente de software que integra varios dispositivos, incluyendo Kinect para el reconocimiento de gestos, micrófonos para el reconocimiento de voz y un dispositivo de proyección grande. Este componente se integró en un prototipo funcional que utiliza la interacción multimodal basada en gestos de voz y manos para la navegación en mapas 2D y 3D utilizando cualquier software GIS. Fue probado usando Google Earth.

Tras realizar un estudio inicial con los usuarios, hemos llegado a la conclusión de que el sistema con interacción multimodal genera mucho interés y expectativa por parte de los mismos y que la experiencia del usuario se ve afectada por la calidad y el rendimiento en el reconocimiento de gestos y comandos de voz.

El uso de los edificios históricos 3D mostrados dentro de entornos virtuales como Google Earth puede ayudar a visualizar los artefactos representados en la escena.

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CHAPTER 1

INTRODUCTION

1.1 General Introduction

In the last 30 years, the importance of maps, as a means of communicating territorial information, has been increased by their use in the data visualization for different domains [1]. Here a map is considered as a symbolic depiction emphasizing relationships between elements of some space, such as objects, regions, or themes [2].

Today technological development, and the technical revolution associated with it, affects the expansion of all sciences, among them social science, archeology, and geography. Cartography is one of the sciences that has been most influenced by this revolution. The Virtual Environment (VE) concept in Geographic Information System (GIS) represents a virtual world, where real or abstract spaces that are shown with the existing objects inside. Hence, the user is inside a digital world, and can explore and analysis objects by dealing with 3-dimensional images, virtual sounds and multimodal interaction [3]. The emergence of increasingly powerful computing tools and the use of new means of communication, combined with the incorporation of VEs, is leading to significant changes in the paradigms for cartographic work. Specifically, the development of so-called Geographic Data Visualization offers a new way of communicating spatial information. In the present thesis, after evaluating and discussing some of the many publications on the subject (Geographic Data Visualization), and discussing the meaning of this technique, an example of an application of new Geographic Visualization methods is presented, through the development of a general system that can be applied to different scientific data.

In conventional cartography, the real world is represented by forms on a two-dimensional image (on paper in the past), simplifying the different entities to form a map. On the other hand, we know as a digital map is generally of much higher value than the traditional map, as the digital version can be merged with other sources of data for analyzing information with a graphical presentation. Objects in a digital map are supported by a set of metadata, accessible for the user to analyze or to enrich the meaning of the map.

A Virtual Geographic Environment (VGE) is a geographic analysis tool that can be used to solve complicated geographic problems and improve geographic conceptual understanding. In brief, the geographic environment is the surface including humans and other creatures who live there. In addition, the different requirements of the information system, like exposing, sharing, editing, analyzing and storing various types of spatial and geographic data, can be represented by the geographic environment.

Today Virtual Geographic Environments (VGE) is rapidly expanding the domains of geographic information visualization and geovisual analytics, using displays that dynamically and interactively combine photos, graphs, text, and maps. Such geovisual analytics not only inform people about economic, political, processes and social phenomena, but are also designed to help space-time inference and decision making, to reframe thinking, to preserve heritage data, and possibly even to change human behavior, as already indicated.

In the last decade, the amount of geospatial data has dramatically increased, due to the widespread use of computing devices and sensors. It has led to the appearance of the concept called Geospatial Big Data, which is defined as collections of geospatial data that exceed the capacity of conventional computing systems [3]. The geospatial data are categorized into three main types: graph, vector, and raster data. Graph data can be shown in network form, while the vector category of data can appear as polygons, lines or points. The raster category of data involves geo-images, which are usually obtained by satellite sensors, onboard plane cameras, or more recently by onboard drone devices and 3D information [4].

This thesis will discuss all details of the data visualizing process in the context of scientific information visualization and present the development of a Scientific data Visualization System (SdVS).

The concept of data visualization can be described simply as a presentation of data in a scene or graphical format [5]. Data visualization allows for decision-makers to see analytic data or summarized data more visually and in an intuitively way.

According to Donalk [6], the visualization concept is defined as the central bridge that connects the content of quantitative data with human perception. The scientific contexts emphasize that the visualization process aim to provide the scientists with optimal tools, which help them to discover the relations and hidden patterns within their relevant data as well as creating visual representations with meaningful properties. Hence, visualization is distinguished by its ability to establish an interaction interface between digital data in computers and human perceptual abilities [7].

The discovery of hidden patterns and unidentified correlations is considered as the main challenge that faces big data. The discovery of hidden patterns and unidentified correlations is considered as the main challenge that faces big data. In this case, and from our point of view we say that advanced visualization can helps analytics processing to discovery hidden patterns and unidentified correlations. This insertion represents an optimal method to solve this challenge and to improve the decision-making process [8]. On the other hand, visual discovering and analysis of big data through real-time visualization cannot be easily attained, due to the variations within the type, semantics, and structure of heterogeneous data, that are involved within big data [3, 4, 8]. Therefore, the presentation of real-time visualization of high spatial resolution data with multiple sources, high-dimensional data, and geospatial data became difficult [9].

The visualization technology in multiple dimensions has become important for efficient data analysis, and that has attracted the attention of scientists in various fields.

A recent study [10] compared and assessed the performance of two-dimensional visualization, three-dimensional visualization, and a hybrid between them. These cases were evaluated based on interest task volume and relative position estimation experiments.

The results obtained from these experiments [10] indicate that the displays that combined two-dimensions with three-dimensions when representing the real-geographic-scenario-based virtual social environment had better performance than the other cases. In addition, these representations allowed integrated navigation and provided higher confidence. The results also show that the spatial proximity, occlusion, orientation signals, and task characteristics of the views were the main factors required to attain a usable and preferred display.

On the other hand, novel experiments were used in [11] to conduct a comparison between two and three-dimensional visualizations. The experiments were intended to determine the advantages and the excellent performance of three-dimensional visualization within multi-lateral tasks. Based on the results obtained, the two-dimensional visualizations behave better

within timeline subscribing, whereas the three-dimensional behave better in the camera navigation. The researchers give attention to one of the most important benefits of visualization, because it allows visual access for enormous amounts of data in easily represented knowledge visuals. Besides, the designed data graphs are typically the simplest and at the same time powerful. The term “geographic environment” appeared consistently on the field of research because it is used to describe any information system that requires analyzing, editing, sharing and exposure of different types of geographical and spatial data.

1.2 Challenges of Archeological and Scientific Data Representation

As mentioned before, the term Virtual Geographic Environment (VGE) denotes a computer-based geographic environment that is designed to understand and fix geographic issues [12, 13]. However, there are several challenges facing users in the VGEs domain. Hence, this subsection aims to highlight some challenges and issues that face users and researchers when building and using the normal structures of VGEs as shown below:

- The complexity of selecting the optimal storage of data to achieve continuous visualization or effective data interpolation and recovery.
- Selecting the optimal way to represent a large number of objects on the same coordinates (providing the end user with a clear view).
- The complexity of adjusting the data accuracy, so it fits with a certain Level of Detail (LOD).
- The complexity of representing the metadata or multi-dimensional data in the identical scene.
- The complexity of creating a three-dimensional archaeological construction using a graphics engine.
- The problem of finding new techniques for human-computer interaction without any restrictions.
- The problem of overlapping that faces the simultaneous visualization of multiple layers, where this problem negatively impacts on the displaying clarity of objects within

layers. Accordingly, novel approaches and systems should be developed to deal with the analysis of current scientific issues regarding GIS.

- The variety of data type is considered as a cause of users' problems, especially when data vary from representation or display pattern into process simulation/modeling pattern or from static type into dynamic type [14]. Hence, developing a novel dynamic geographic model is necessary to overcome the dynamic changes that happen on the daily base [15].

The following five points can summarize the contributions that are added by this work to solve the literature problems:

- Suggesting six novel visualization paradigms that represent several objects at the identical position and deal with various data.
- Overcoming the overlapping problem by suggesting an improved multi-layer position.
- Suggesting a sub-place dialogue paradigm that reduces the time required to extract data from the particular database and will improve the performance of the suggested system.
- Developing new multimodal interaction techniques to access multidimensional visualization without restrictions.
- The SdVS system has applied dynamic models of visualization, which positively affects the interactivity and usability of the system.

Consequently, the researcher has applied new techniques and paradigms to visualize archaeological data smartly and uniquely through the use of the Google Earth program.

Van Asperen et al. and Patterson in [16, 17], tested the performance of three GIS applications (NASA's World Wind, MSN Virtual Earth 3D, and Google Earth) in distributing geo-information to users depending on the Open Geospatial Consortium (OGC) proposed standards. Google Earth proved technically superior to others GIS applications. Because of these studies, we have chosen the Google Earth application to implement the tool as an engine for VGE.

In addition, thesis makes suggestions and proposes new human-computer interaction techniques, in order to permit users to use their gestures and voice.

Further aims of this thesis are to present and promote innovative concepts, methods, technologies, and tools for the visualization data and human computer interaction, tested as a

Cultural Heritage application. In addition to facilitating dialogue in the Geomatics scientific community, we open up other related fields of research, such as computer graphics, conservation, restoration and management of cultural heritage.

Besides suggesting new techniques for Cultural Heritage with respect to recording, documentation, representation, monitoring, and management by complicated information systems, this makes a wide scientific discussion for the methods adopted of processing and data acquisition having an increasingly important value.

1.3 Thesis Overview and Goals

Visualization is considered one of the most critical research communication and presentation components, because of its capability of gathering huge amounts of data into effective graphics [18]. For the human brain, it is easier to comprehend an image versus words or numbers [19], hence, using graphics effectively is considered an especially important topic for the academic literature. The increasing quantity and accessibility of data [19, 20] require effective ways to analyze and communicate the information that datasets contain in simple, easy-to-understand formats. Visualization serves two major purposes, data analysis and data presentation [21, 22, 23, 24, 25]. So the objective of any graphic in the context of scientific data and presentations is to convey information effectively. Therefore, our ability to visualize scientific data has evolved significantly over the last 40 years.

As a result of the thesis, we have developed a general visualization system called Scientific data Visualization System SdVS. This system has new paradigms for visualization. in addition, we create and apply novel human-computer interaction techniques on these proposed new paradigms.

The SdVS may be used to improve visualization design and scientific data presentation. Adhering to this system will generally improve the presentation of scientific data, and subsequently, the communication of research outcomes in different domains.

- The system developed in this thesis is the result of a very general process to improve scientific data visualization in VGE.
- SdVS allows using the variety of scientific data in different domains so that that other visualization programs can be generated through it.

- A prototype of this system developed and applied in archeological data was used as a data reference (case study).
- This system, called "Archeological Visualization System (ArVS)", was developed and implemented using data from archeological locations in Spain and Jordan. It can be used for any other archeological data, through the application of visualization paradigms and interactive techniques of the SdVS program.

The ArVS program is the result of applying the SdVS program to archeological data. This enables visualization of the archeological data, which contributes to the dissemination of archaeological information easily, and supports the protection and preservation of heritage and archeological data in all countries suffering from the destruction of structured archeology and information.

Consequently, this enables the ArVS system to help end users and archeologists explore the data and analysis of excavations in a handy way, because the system provides access to the excavation database, and automatically refreshes visualization whenever the database is changed, which could allow making discoveries that lead to new investigations about the excavations implemented [26, 27].

Additionally, the system was utilized as a new tool which set focus on two critical points in the scientific fields.

The first point focused on applying novel methods and paradigms proposed to visualize archeological data and provide 3D building images of the archeological locations, presenting all critical details and designs through the use of Google Earth. Furthermore, that fact could contribute to heritage, and the revival of archaeology locations, by preserving the historical data stories and presenting them in new and smart ways, in preparation for the expansion of this project and use in the middle east countries.

The second point in ArVS is focused on how to create new Human-Computer Interaction techniques (HCI) to employ in GIS and archeology programs, to enable the users to use their gestures, voice, etc. to navigate inside the VGE instead of using the traditional keyboard or mouse interface.

A similar contribution was established to give the users the ability to do virtual tourism at any historical place in the world and gain knowledge behind the monitor of a computer without charges or travel difficulties. This can help to make a new generation conscious of the value of archaeological and historical data, which is positively reflected on the communities.

In summary, the ArVS system provides access to the excavation database and automatically updates the visualization, whenever the database is changed, which enables archaeologists to visualize data inside a VGE (3D geographic environment such as Google Earth), making possible the new way of interaction between the scientific and the visualization system.

The thesis answers five fundamental questions regarding archaeological GIS systems:

- How to adapt the resolution of data to fit them in a specific Level of Detail of the visualization?
- How to integrate two and three-dimensional representations into the same scenes?
- How to represent many objects in the same coordinates without overlapping?
- How to apply the new visualization methods?
- How to create and apply new, non-traditional human-computer-interaction techniques with the visualization methods suggested?

1.4 Structure of the Thesis

This thesis is structured as follows:

- Chapter 1 gives the introduction, describes the motivation, and explains the SdVS system and its visualization paradigm and human-computer interaction techniques that are presented by this work.
- Chapter 2 describes the background, providing an overview of the main components, as well as the models, programming languages and graphics engine used in this work.
- Chapter 3 describes the principles of the Science data Visualization System SdVS in this work, through explanations of the framework, data flow, and flowcharts.
- Chapter 4 describes the methodology proposed for the visualization paradigms in this work when applying the SdVS on archeological data to produce a new application called Archeological Visualization System ArVS.
- Chapter 5 presents and describes the results of new human-computer interaction techniques developed as part of our ArVS system.

- Chapter 6 presents the assessment results of implementing and validating our ArVS system and highlights the implications of this work.
- Finally, conclusions, limitations and future work are provided in Chapter 7.





CHAPTER 2

BACKGROUND

2.1 Introduction

Information visualization has emerged as an independent research field which aims to amplify cognition by developing useful visual metaphors for abstract mapping data [28].

Visualization is the interface between human perception and data quantitative content, where the visual display process for the Geo-data can be easily and readily interpreted and understood. It is a necessary component for the scientific route from data to understanding and knowledge. Visualization is necessary in guiding the choice of applicable algorithms, the process of data mining, and the elimination bad data from analysis [6]. The goal of a visualization process is to provide tools to analyze and to understand the data and their relations in order to provide support for making decisions. The main benefit of visualization is developing a bridge interface between the cognitive and perceptual abilities of humans and the digital data within a computer [7].

The concept of big data has emerged due to the increasing volume of data available for research. Big data is a novel paradigm providing abundant opportunities and knowledge to enhance decision-support applications, and to allow research with unparalleled value for digital applications involving engineering, sciences and business. Big data includes the flood and overflow of digital data presented in digital sources like social networks, numerical modeling, digitizers, internet, sensors, mobile phone, scanners, e-mails and videos. Various types of data are involved in big data, including sounds, images, geometries, videos, texts and mixtures of these types [29].

The visualization of big data is an effective technique to enhance the process of decision-making, where it is able to reveal unidentified correlations and hidden patterns [8].

However, big data involves heterogeneous data that varies in its semantics, structure and type, and this makes the developing and presenting of real-time human interaction and data visualization a difficult task [8, 30, 31].

In recent years, the volume of geospatial data has greatly increased. This has led to the concept of Geospatial Big Data, which is defined as geospatial data that exceeds the capacity of present computing systems [3]. As we mentioned before this Geospatial data has three main forms; graph data, vector data, and raster data.

Within this chapter, several aspects of data visualization will be reviewed. These include multidimensional visualization, Virtual Geographic Environments (VGE), Archaeological Visual Analytics, Multimodal Interaction, Visualization Tools and Spatial Data Visualization. Some applications of data retrieval and data visualization will be described. The main advantages provided by a visualization process will also be explained.

2.2 Geographic Information System (GIS)

According to Aronoff [32], GIS is defined as a computer-based system that has been developed to deal with geo-referenced data through the following capabilities:

- Data analysis and manipulation.
- Data preparation and capture.
- Data presentation.
- Data management, involving maintenance and storage.

Nowadays, GIS also incorporates capabilities of retrieval and dissemination of data from networks, usually using web services that implement standard interfaces for data interoperability.

GIS is used in different contexts, including environmental management and spatial planning to support decision-making [33]. It can also be used to overcome human errors, costs and time-consuming problems. Governmental organizations, defense agencies, security agencies and utility companies are considered the main domains of GIS applications [34]. GIS has also been incorporated into urban management, where the scale and scope of problems within

urban areas and the combination of different data models enhance the value of GIS in visualization, complicated analysis, and spatial data management. The structures of data that are generated by GIS help in constructing urban systems for information management and spatial analysis, due to the capability to manage different formats of spatial data [34].

Zollmann et al [35] have studied the application of GIS in “Situating Visualization Techniques”. Their study showed that there are many challenges faced by these techniques, such as restricted spatial relationships understanding, information clutter, legibility and restricted visibility.

Stifter and Milano [36] present an open source project integrating OSGIS with PSAT. OSGIS is an open-source application that involves several tools for GIS visualization, analysis and drawing, while PSAT is a popular application for the analysis of power systems. The objective of this integration is to show how the integration between open-source applications can produce interesting results in a short period of time. Moreover, GIS has been introduced to the health field, where it provides public health professionals with a novel collection of tools to help them observe and respond to major health problems. It is also used to determine the spatial trends, assess statistical hypotheses, correlate spatial data, determine clusters of disease and provide data analysis with the required mapping and visualization [37].

Villarroya et al. in [38] develop a framework called SODA, that enables spatio-temporal declarative analysis over large warehouses of observation data. This integrates the management of entities and samplings within a simple data model based on the well-known mathematical concept of function. Observation data semantics are incorporated into the model with appropriate metadata structures.

Regueiro et al. [39] designed, implemented and evaluated a framework that enables the virtual integration of heterogeneous observation data sources through a Sensor Observation Service (SOS) standard interface. This framework uses a well-known Mediator/Wrapper virtual data integration architecture, enabling direct access to the current data supplied by the data sources. The framework has been validated as an OGC compliant technology to publish the meteorological and oceanographic observation data generated by two public agencies of the regional government of Galicia (Northwest of Spain).

In addition, Villarroya et al [40] tackle the problem of homogeneous access to sensor data in data monitoring and analysis applications. They propose the design and implementation of a framework called GeoDADIS for the development of data acquisition and dissemination servers. Those servers are commonly used in monitoring applications, as they perform as

gateways between decision support and data visualization technologies used in application development and the heterogeneous collection of protocols and interfaces available in the industrial area for sensor data access.

Geographic Information Systems are used as a tool in several archaeological studies. Any archaeological study implicitly involves a volume of factors and relationships whose proportions can overwhelm the analysis capabilities of professionals. So it may be advantageous, in the study of a specific cultural process, to establish a hierarchy of essential elements and consider their analysis from a dimensioned viewpoint. In this way, the reality is simplified in order to facilitate the understanding of the phenomenon or relationship under study and provide a clear image of the problem.

As examples of these archeological studies, [41] at the Massachusetts Institute of Technology have developed a methodology for superimposing historical and present-day industrial land use data layers with demographic information and public health data. The goal of this study is to identify and to possibly define a historical relationship between present-day public health concerns and past practices of land use within an urban environment.

In addition,[42] describe a Web Geographic Information Systems (Web GIS) developed for handling and promoting information about archaeological sites. This system is one of the goals of a more comprehensive research project. The aim of such research activity is the development of an information system enabling heterogeneous users to exploit GIS capabilities and web-accessible data. Besides, Technological Center of Supercomputing of Galicia has broad experience working with GIS technology. Which is developing and has been involving, and the implementation of various projects related to the fields of archeology, such as [43].

Besides that, Jovanović [44] has reviewed a GIS application for tourism planning, in which GIS was used for bringing the georeferenced data (spatial and non-spatial) of the geographic locations Zlatibor and Zlatar (Serbia) into digital maps. Each object is assigned to a thematic layer, and each layer combines related objects like roads, buildings, protected areas and watercourses.

2.3 Multidimensional Visualization

Data can be categorized according to the function of their dimension, based on the number of attributes, which differ from one data set to another. Data with three attributes or more is called multi-dimensional data and are visualized by multi-dimensional visualization

techniques. Parallel Coordinate Technique (PCT) is an example of a multidimensional visualization technique. This technique displays the multi-dimensional space as polygonal lines and then maps it into a 2D display [45].

Multidimensional visualization is considered a significant sub-field of scientific visualization. The goal of multidimensional visualization is to identify the main relationships and trends between multidimensional sets of data after visually summarizing them [46]. Dataset with a high dimensionality and enormous size are hard to visualize using a single visual space. The main challenge faces by multidimensional visualization is displaying data sets in intuitive structures with whole attributes at the same time and without overlapping [47].

The performance of visualization processes for two-dimensional and multidimensional displays was presented in [10] and [48]. Several experiments for interest task volume, estimation of relative position and orientation were conducted to compare the performance of visualization in each case. The results indicated that integrated displays (2D display with 3D display) support integrated navigation, provide higher confidence and have better performance. In addition, an appropriate display can be attained by spatial proximity views, occlusion, orientation signals and task characteristics. On the other hand, Amini et al. in [11] presented a comparison between two and three-dimensional visualizations by novel experiments. The experiments aimed to identify the advantages and evaluate the performance of three-dimensional visualization through more complicated tasks. The study confirmed that the performance of two-dimensional visualization is better in timeline supporting, while 3D visualization is better in camera navigation.

On the other hand, Levkowitz and Oliveria [49] and Keim [50] categorized the techniques of multi-dimensional visualization into three categories: icon-based techniques, which use visual variables like hue, size, shape and color to map the data into icons via encoding; geometric techniques, which project data into 2D or 3D Euclidean space using visual data, and pixel-oriented techniques, which represent data values as pixels, where the color of these pixels is used to encode the data values.

2.4 Virtual Geographic Environment (VGE)

In general, a VGE is defined as a novel multi-disciplinary initiative which integrates information technologies and geoinformation sciences. It also represents a perfect interface for scientists to study and represent geo-information [51]. VGE aims to solve complex ge-

ographic problems and understand all sides of the geographic world. It has been recently applied to three scientific objectives for Geographic Information Science (GIScience); public participation, simulation of dynamic phenomenon and visualization of multidimensional data [52].

According to Huang et al [51], VGE can be considered as:

- A novel multi-specialty initiative that integrates information technologies with geosciences information.
- A virtual demonstration of the world that allows individuals to interact with a huge amount of cultural, natural and social information about physical environments.
- An integration of the 3D virtual Environment world with the human reality world.

The comprehensive structure of VGE should involve four major components: collaborative, simulation, modeling and interactive. The functions of these components are, respectively; designing the collaborative tools, implementing the geographic simulation, modeling and organizing the geographic data, and interacting with that data [53, 15]. The structure of a VGE is shown in Figure 2.1.

In addition, the developer can add to the structure of VGE a new two components called (geographic process model base and a geodatabase). Furthermore, they can construct the virtual geographic scenarios to explore the geographic phenomena and address the geographic issues [54, 55] for the researchers.

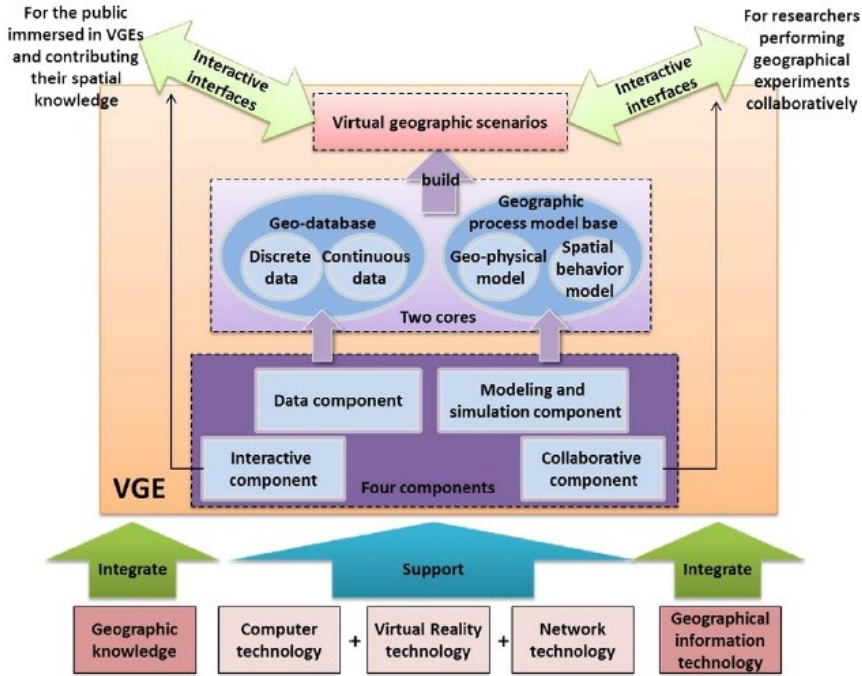


Figure 2.1: General Structure of VGE [52].

A VGE applies the power of visualization methods to geographic information. However, VGE lacks a suitable platform for analysis and simulation of three-dimensional geographic spatial entities and phenomena simultaneously. The actual world is a 3D space, and this requires 3D visualization techniques. Virtual Globe has been designed and developed to overcome the VGE platform problem, [56]. In addition, the expanded development of internet technologies, wide area computer networks, and standards for data interoperability, have led to developing the Distributed VGE, which aims to allow multiple users to participate and share an identical virtual geographic workspace [57].

Moor and Russwurm [58] have developed a new application based on utilizing VGEs, where the usual specific virtual environment has been replaced with a non-specific naïve geography environment. Hence, users can deal with geographic environments in a more comfortable way. In general, the data environment is mostly constructed on the base of a traditional GIS, which is mainly focused on data management and visualization based on a cartographic model [59]. This leads to several obstacles for data representation and computation.

Lu et al [60] have defined the main obstacles faced by the construction of a data environment when the environment is used to represent the geographic mechanisms, processes, and characteristics within a consolidated framework. These obstacles of data representation and computation are summarized as follows:

- The cartographic models represent spatial objects with geometries, and organize data into different feature layers.
- The spatial and temporal dimensions are separated. It is challenging to support both continuous and discrete geographic processes [61, 62, 63].
- The present GIS data organizations are highly unstructured. Since the dimensions and structural complexities are increasing, the contradiction between high-dimensional unstructured data representation and linear data organization in computers is growing obvious.

Chen et al [10] overcame these obstacles using VGE, which is able to join information involving graphs, time series, geometrics and algebraic equations. The suggested solution was based on converting the basic data environment into an integrated model rather than a normal cartographic model. The suggested approach was able to include various information and elements within a comprehensive model.

Villarroya et al, has unified in an environmental data model, raster and vector data types to improve the efficiency of spatial queries, developing an specific spatial query language to run in a distributed and parallel big data framework [64].

2.5 Archeological Visual Analytics (AVA)

Visual Analytics (VA) is defined as analytical reasoning in science supported by visual interactive interfaces. It integrates interactive visualizations with automated techniques of analysis for reasoning, decision making and effective understanding on the basis of complicated and huge data sets. VA aims to create techniques and tools to allow people to [65]:

- Provide understandable, defensible and timely assessments.
- Derive insight and synthesize information from conflicting, ambiguous, dynamic and massive data.

- Allow effective communication of assessment for action.
- Identify the predictable and discover the unpredicted.

In general, visual analytics builds on a variety of related scientific fields. At its heart, VA integrates information and scientific visualization with data management and data analysis technology, as well as human perception and cognition research [65]. VA is also considered as a discipline concerned with logic and analytical processes, backed up by highly-interactive graphic interfaces. The decision making can be backed up by analyzing, integrating and searching data. The main components of VA are [66]:

- Distribution and presentation.
- Interaction technologies and visual-demonstration.
- Analytical reasoning.
- Transformation and data demonstration.

The science of archaeology is concerned with analysis and recovery of artifacts and human remains of prior societies to understand the human behavior, social organization and architectural structures of these societies. During prior decades, collection methods for modeling, visualization, analysis, and repositioning were enhanced and developed directly by archaeologists. More recently, GIS technology and VA have been introduced for decision making, modeling and analytical development of applications in this area [67, 68, 69, 70, 71].

One of the software applications of VA in the archaeology area was presented by Huisman et al [67], where the Space Time Cube (STC) software was used for space-time archaeological data analysis and visualization. The concept of space-time cube originates from cartography, where it refers to a geographical representation where time is used as a third dimension [72]. The study presented the initial outcomes of geovisual analytic functions developed for archaeological examination with this software.

Tsipidis et al [73] proposed techniques to perform visual analysis for complicated archaeological data in a variable environment of visualization. A simple GIS interface has also been suggested to perform dynamic presentation, querying and 3D visualization for temporal relationships and characteristics and to improve the interaction of users with the data.

Koussoulakou and Kraak [74] presented an archaeological STC application to support the visual analytics. The application focused on the exploration of spatial-temporal features for

the archaeological locations. The study confirmed that the STC can identify the complicated relations between different artifacts, which were extracted from various historical eras at specific time.

Deufemia et al [75] presented the Indiana Finder System (IFS) for data visualization. The system allows archaeologists to study and investigate different warehouses of drawings and documents to conserve the rock art of cultural and natural historic sites. Visual analytics was supported by IFS to perform investigative analyses, like detection of novel insights, revealing of explanation anomalies and explanation of novel archeological discoveries. The integrated environment of IFS allows the archaeologists to learn, discover and examine the textual drawings, pictures and documents relevant to the carving of rock.

2.6 Multimodal Interaction

Multimodal human-computer interaction refers to interaction with the virtual and physical environment through natural modes of communication [76]. Systems based on multimodal interaction try to recognize the natural forms that arise from human behavior and language through recognition technologies. Furthermore, efficient and natural multimodal interaction can be provided by multimodal interfaces which are able to enhance the efficiency of task development [77]. Multimodal interaction is based on haptic devices, gesture recognition and speech recognition technologies. It represents a major element in multimedia visualization. And its objective is to support all communication between machines and humans as well as to enable interaction between humans [78].

Multimodal interfaces have several advantages [77] These interfaces can:

- Provide use of input modes in a flexible manner, such as integrated or simulated use.
- Support enhanced efficiency, especially when manipulating graphical information.
- Provide users with several options within their interaction techniques.
- Absorb a larger number of environmental situations, tasks and users.
- Adapt to continuous variations in the interactive technology and environmental conditions.
- Provide improved error prediction.

- Support simpler and shorter speech words, and thus enhance the accuracy of speech recognition.

2.7 Visualization Tools

A variety of software packages has appeared in recent years to support interaction between humans and geographic information data bases. These include NASA WorldWind, Google Earth, Yahoo Maps and others. Google Earth provides earth visualization with high quality imagery data through the Internet, while WorldWind provides imagery data not only for the earth but also for Mars, the moon and others [56]. The above software, and other applications like GISs and Geo-Visualizer, have been used as data visualization tools in many different fields. Within this section, a brief description is given of these tools and their use in data visualization.

2.7.1 Google Earth (GE)

GE is a free web-based application that joins Base Surface Imagery (BSI) with a universal Digital Elevation Model (DEM) in order to generate three-dimensional representations of the earth. It is considered as a robust tool to analyze, track, view and visualize events, surface processes and geological characteristics. It also provides the users with a canvas that enables them to append their geo-spatial data through the Keyhole Markup Language (KML) in order to generate more dynamic visualization [79].

GE has become one of the most robust tools for geological visualization and modeling. One of the most useful and interesting Google Earth characteristics is Google Street View (GSV). In the last decade, there has been a rapid expansion of systematically gathered street-level imagery available on the internet. The most well-known collection to date is (GSV) [80].

Street View started as part of Google Maps but has expanded rapidly since. Currently it includes the ability to virtually wander through the street-level environment, thus enabling a wide range of uses including virtual tourism, real estate search, travel planning, business search, and enhanced driving directions [81].

Another use of GSV is to visualize geological objects such as rock masses and layers for analysis studies like [82, 83]. This application has been used in different areas of research. For example, Mei et al [84] used GE to show a real solution for constructing suitable 3D

geological models for rock masses. The Haut-Barr region in France was selected to conduct the study, where GE was used to determine the features of this region. The scales and shapes of rock masses in Haut-Barr have been identified to acquire the layer pattern of rock masses via novel use of GSV. The model obtained allows identification of the rock masses construction by visualizing the rocks bodies.

Research by Wood et al [85] is another example of GE implementation, where GE has been used to establish a mash-up case study for geo-visualization in order to create an interactive encoding synthesis using LandSerf, PHP and MySQL languages. In addition, Standart et al [86] utilized GE to develop a novel web service called Vis-EROS. The web service aims to visualize all global download requests related to satellite images and preserved by the center of Earth Resources Observation and Science (EROS). It also enables users to easily and rapidly evaluate and visualize all related geographic information involved within the download requests on certain dates.

2.7.2 NASA Web World Wind

WorldWind is a free, open source API for visualizing and hosting geospatial data. WorldWind is platform-independent, and can be configured to deal with any format and size of data. This technology can be freely used by commercial industry, national and local government agencies, space agencies, and others. It enables developers to frequently enhance and implement functionalities (analytical tools) to raise the sophistication of analysis and to accommodate changing requirements [87].

Brovelli et al. [88] utilized the framework of NASA WebWorldWind to design a novel web application to visualize multi-dimensional telecommunication and social media data. Global telecommunication services create an enormous volume of real-time data, in which the “Telecom Italia Big Data Challenge 2015” was used to retrieve the collected data of the system.

The data provided gives information about telecommunication events, i.e., SMS, calls and internet usage. All entries have a timestamp expressed in milliseconds. Telecom Italia provided a geo-referenced irregular grid, for some cities in Italy, where an id represents each grid cell.

The application aimed to visualize the data optimally in order to view this data within the three-dimensional environment. The application enables the end users to understand the data rapidly as well as showing the real context for that data. Also, the application allows users to

deal with different data types, import the dataset of this data through a suitable structure of data, and mix it within the virtual globe of WebWorldWind.

NASA WorldWind has been introduced to the cultural field, especially to cultural historic sites. In Brovelli et al [87] an application is described using NASA WorldWind technology to visualize historic sites and to improve the experience of tourists. This application supports access into several cadastral maps dating from the eighteenth century in order to guide the tourists [89, 90, 89]. Another project based on ad-hoc WorldWind conditioning has been proposed by Brovelli et al [87] to encourage tourism in the Via-Regina region, which is located between Switzerland and Italy. The results indicated that the application is an important tool to improve the experience of tourists and to raise cultural awareness as well as being an optimal tool for tourism applications within the virtual globe.

2.7.3 GeoVisualizer

GeoVisualizer is an extensible and flexible application developed to represent geo-referenced 3D and 4D data. Non-visualization experts can use GeoVisualizer to get brief impressions and generate meaningful representations for their geo-referenced data. The application is based on the SDK infrastructure of NASA WorldWind and the technology of Java Web Start [91].

GeoVisualizer has two main components: GeoVisualizer-Core and GeoVisualizer-UI. The latter component provides the graphical user interface with required functions and methods. This component is able to manage and integrate the standard web services for interoperability proposed by the Open Geospatial Consortium (OGC), like Web-Feature Service (WFS) and Web-Map Service (WMS). In addition, GeoVisualizer-UI provides the user with a wizard for visualization (VisWiz) that helps the user to obtain 4D and 3D demonstrations depending on the nature of the data. It also supports stereoscopic displays, which help to show the visualization by actual three-dimensional hardware [92].

The other component, Geo Visualizer-Core, supports an extension to provide interface specification and basic techniques of visualization, with novel visualization techniques techniques by combination with a GPS device and integrate sensor data and traditional sources like Web-Map-Sevices and 3D-content from KMZ files in order to combine them in a way that can be used for various kinds of urban planning projects. Based on representation this geo-data by “Scrolling 3D Bars” and Animated Polygons” for various sets of geo-referenced data. It also supports color encodings and provides different color palettes. Service Provider Interfaces (SPI) is used within GeoVisualizer to combine data export and import modules with

user-specific visualizations. The integration between SPI and Java Web Start technologies enables the use of local, private visualization concepts as well as the constant up to date public components of GeoVisualizer [92].

2.8 Spatial Data Visualization

The visualization of spatial data enables users to understand and to interpret the outcomes of spatial-data mining as well as to get an enhanced understanding for the patterns revealed [93]. However, the increasing data richness and dimensionality within the representation of each object increases the complexity and the challenges faced by the visualization process. Therefore, Lu et al [94] suggested TerraFly GeoCloud, which is a system to visualize and analyze spatial data. The system is able to overcome the challenges of visualization, involving flexible interaction of user and multi-dimensional visualization. It also combines data visualization with spatial-data mining to detect hidden patterns.

During the last few years, many technical methods of visualization have been developed, including spatial data and spatial data-mining visualization methods. Both of these aim to identify what the spatial data represents, find relations among geography entities and discover new knowledge. The visualization process related to spatial data-mining consists of three main tasks: feature determination, feature interoperation and feature comparison [95].

Sunil Singh and Preetvanti Singh [96] present a novel web prototype based on spatial visualization. The prototype is developed using the Microsoft .Net platform with a set of open-source geospatial bundles in order to employ the web browser within interaction and visualization of spatial data. The insertion of geospatial and open-source tools within the prototype enhances the speed of implementation without adding any cost for input software.

In addition, Zhang et al [97] suggested TerraFly GeoCloud which is an interactive system to visualize and analyze the spatial data. The system aims to enable the end users to analyze and visualize the demanded spatial data. Also, it allows the sharing of results obtained from the analysis via URLs [98]. Yue et al [99] suggested an approach of spatial Data Infrastructure (SDI) to apply spatial analysis to social and scientific data.

2.9 Applications of Data Retrieval and Visualization

GeoLife is an example of a data retrieval and visualization social networking service, where it operates to understand, fast retrieve, organize and visualize the GPS track logs. This

visualization service is able to understand and share the trajectories of people depending on the raw data of GPS. It also utilizes users uploading behavior to index the trajectories of GPS, time query and spatial range to track the search, and digital maps to visualize GPS data [4].

The prototype system of Jeong et al [22] is another example of visualizing, retrieval and querying datasets applications. The system is characterized by its ability to manage enormous volumes and heterogeneous layouts of datasets. It also has a simple structure based on a metadata approach, so no experience or knowledge is required to deal with it. The system engine, which is based on Java and the metadata mechanism, allows the users to reach the diverse data structures from different heterogeneous hydrological sources and then retrieve them.

Pispidikis and Dimopoulou [100] designed another application for data retrieval and visualization, called 3D WebGIS. The application aims to visualize and retrieve the data of CityGML (an ideal standard to exemplify the 3D models of city) based on their semantic and geometric features. The experiences show the ability of 3D WebGIS to visualize data through the web based on their architecture and web technologies

2.10 Advantages of Data Visualization

The quick expansion in data generated every day has led to several developments in different areas, involving decision-making, quick analysis, literacy and accessibility. These developments encourage the use of data visualization, which plays a great role in increasing evidence usage in research, enhancing the understanding of different types of data and decreasing knowledge gaps [101]. The major advantages added by data visualization are summarized by the following points [45, 102]:

- Save time.
- Enhance the process of decision making.
- Enhance the sharing of information.
- Provide enhanced analysis of ad-hoc data.
- Provide the end user with self-service abilities.
- Minimize the load on IT.

- Ability to explore huge sets of data.
- Provide the users with interactive interfaces.
- Ability to detect the hidden patterns.
- Ability to analyze huge volume of data.

2.11 Conclusion of Chapter

This chapter discussed the main concepts of data visualization and showed the main applications of this process within various fields, including health, archaeology, business, society and science. Due to the greatly increasing volume of data, the visualization process has become very necessary to manage, query, analyze and visualize this data. Also, the large size of the data and the variety of data make the visualization of data using traditional techniques and tools inadequate. Thus, multi-dimensional visualization has become the optimal choice for this purpose. Several applications and systems of visualization have been reviewed within the chapter showing their role, importance and obstacles. In addition, the chapter showed the importance and the main benefits of data visualization.

CHAPTER 3

SCIENTIFIC DATA VISUALIZATION SYSTEM (SDVS)

3.1 Introduction

In this chapter, we present the description of a Scientific Data Visualization System (SdVS). This system integrates multiple paradigms for visualization and human-computer interaction that can be applied in different scientific fields.

From a methodological point of view, we are applying the SdVS from a new critical visualization and interactive perspective, in which scientific data is the core, reflected on communities development through gaining knowledge, using new and dynamic ways to represent and interact with data to provide efficiency and quality.

3.2 Scientific Data Visualization System (SdVS)

The SdVS design incorporates paradigms and techniques for geodata visualization, navigation and human computer interaction inside GIS engines like a GoogleEarth. Where any geo-scientific data can be visualized over the terrain surface. The general architecture of SdVS is presented in Figure 3.1.

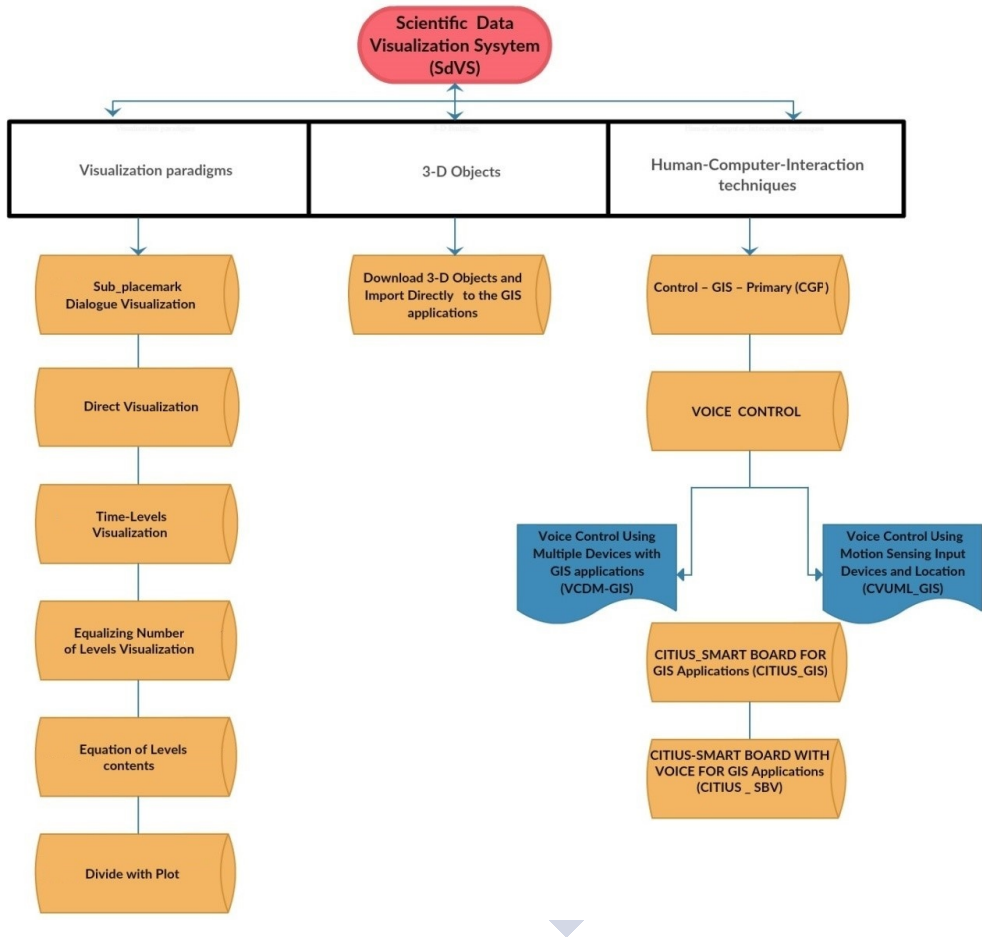


Figure 3.1: Scientific Data Visualization System structure.

In this Ph.D. , we are searching for new possibilities of navigation and data access that may be achieved using SdVS, which facilitates interaction with maps and the transfer of knowledge by new methods of visualization.

The use of SdVS gives the researcher higher efficiency in the communication and knowledge transfer of scientific data, because the user can provide its logic for the use and analysis of the information (depending on the possibilities of the SdVS system). Additionally, the new interaction technologies allow the user the possibility of interacting more directly with

the framework, which makes it possible to improve the visualization and data communication process.

In this thesis, we propose and implement a Scientific data Visualization System (SdVS) as a general framework for visualizing and interacting the geodata, by applying new scientific data visualization paradigms and human-computer interaction techniques (see Figure 3.2). Further, we use archeological data to test the SdVS system, developing a new sub-system called ArVS which has been successfully tested, as we will explain in chapter four.

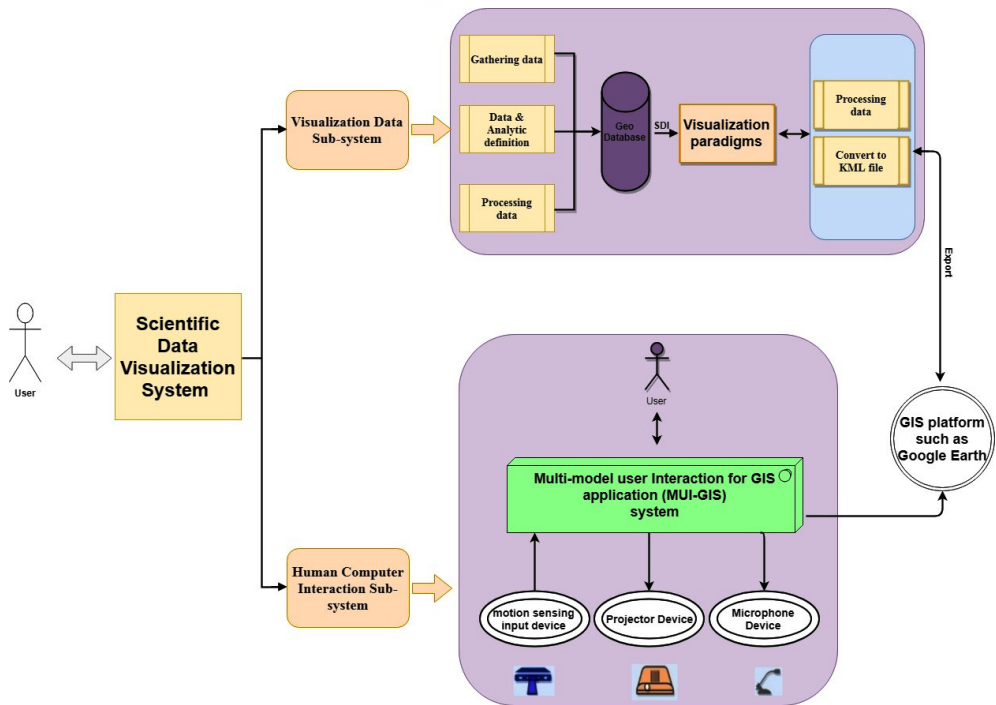


Figure 3.2: The general structure of the Scientific Data Visualization System

As we shown in Figure 3.2, the SdVS provides a general framework for the visualization and interaction with Geo-data. We can conclude from the figure that the general properties of the SdVS as follows:

- Data visualization: the SdVS visualization process is focused on the study of how to visualize Geo-data by the incorporation of dynamic maps and interactive maps and

the Geospatial Virtual Environments, using dynamic visual variables such as display time (used in the temporal dimension of dynamic location). Access and exploration of databases, where SdVS has been integrated with technologies for the storage, access, and analysis of georeferenced information.

- Access and exploration of structure databases: SdVS has been integrated with technologies for the storage, access, and analysis of georeferenced information and convert in to KML file format.
- Development of paradigms for visualization: this is one of the most explicit objectives of the applicability of the SdVS. Through the analysis and integration of all its aspects, it is possible to develop paradigms that allow expanding the possibilities of analysis and compression of spatial phenomena through application of various types of scientific data.
- Interface design: In this context, we divided interfaces into two types (Human-computer interaction and Data) interfaces. The interfaces used in the SdVS can be controlled by using traditional ways, gestures, and voice for the processing and visualization of geospatial information.

3.2.1 Visualization paradigms

Scientific Visualization (SV) is concerned with the visualization of three-dimensional phenomena (medical, architectural, geographical, meteorological, biological, etc.) to aid in the analysis, understanding, and manipulation of data. Since its beginning in the early 90's, the techniques of SV have aided scientists, engineers, medical practitioners, and others in the study of a wide variety of data sets including, for example, the geoinformation being linked to cartography, that can facilitate the interpretation and analysis of the most significant aspects of spatial information [103, 104].

SV is a sophisticated tool that demands art, imagination, and intuition in its applications. It has an essential theoretical basis, in which the cognitive process, through research and analysis of information and its applications, is related to communication (through the use of new communication techniques) and formalization (through the use of existing computer technologies) [105, 106].

Different paradigms can be used to visualize a database query result. Users are dealing with data, and they need to represent over the earth surface, in our SdVS, a subset of this data

that satisfies a set of conditions. After the system retrieves the correct data from the database, problems could appear due to the number of data objects that share the same position. Obviously, this will depend on the Level of Detail (resolution) that the user has established in the particular view, where data must be shown.

As we mentioned earlier, SdVS is a Web-based visual, interoperable, and scalable platform that can access scientific data visualization fields using Google Earth (GE) as a familiar graphical interface. Google Earth is a cloud-based platform for planetary-scale geospatial analysis [107], and it has many features. One of the most commonly used features in Google Earth is the placemark. This marks a position on the Earth's surface [108], and we use it in the current work (see Figure 3.3).

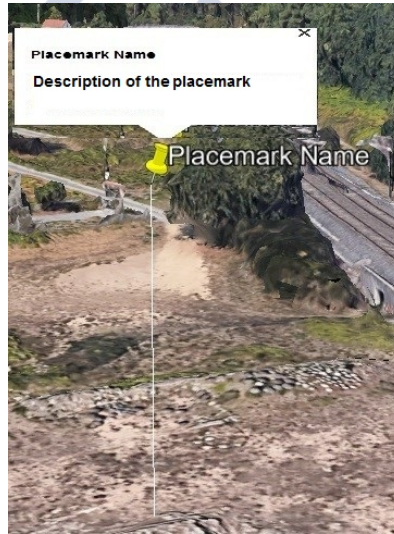


Figure 3.3: Placemark structure.

In the following sub-sections, we will summarize the new visualization paradigms for scientific data visualization that we introduce and implement in SdVS.

Sub-placemark Dialogue Visualization Paradigm

This paradigm was created to visualize big geographic data precisely. The paradigm represents big geodata, where sub-placemarks are created and classified based on similar coordinates.

The sub-placemark dialog visualization paradigm deals with objects through the main placemark interface (place of this interface in the description of the placemark see Figure 3.3). The sub-placemarks will be displayed as a result of a query and each one will contain the numbers of elements (artifacts) which have the coordinates of the sub-placemark.

The size of each sub-placemark icon is proportional to the number of objects that it represents. The system calculates the size directly in two steps. First, the data are selected with the main placemark interface; then, the size is computed depending on the number of elements or objects that have the same coordinates. The sub-placemark which contains the largest number of elements will have the largest icon.

The number of elements contained in the sub-placemark will be shown at the new interface for the user to deal with it. The system will search and show the results only for the sub-placemark that was chosen by the user, thus improving the efficiency of the system (see Figure 3.4).

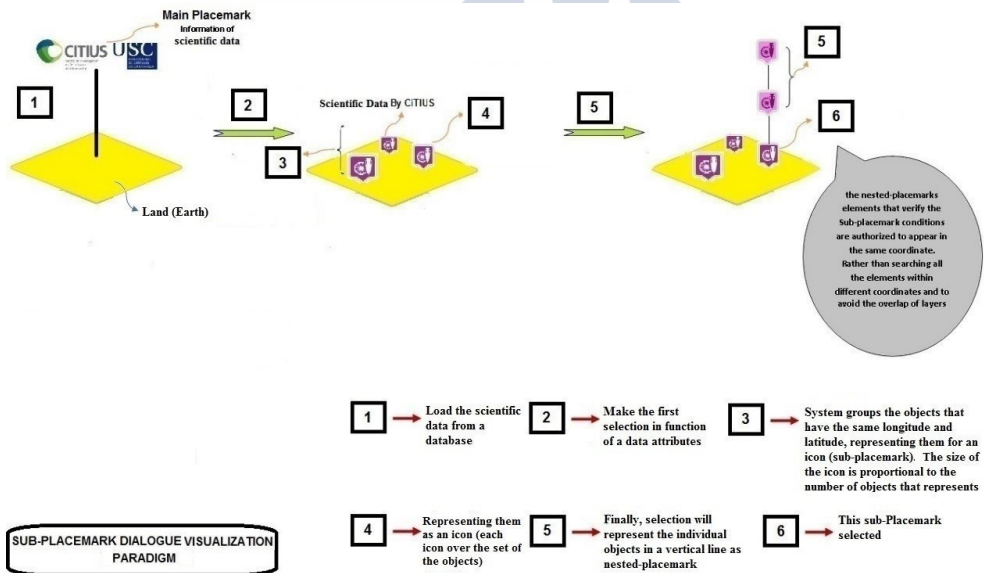


Figure 3.4: General diagram of Sub-place dialog Visualization paradigm.

Direct Visualization Paradigm

When visualizing geodata, the problem of viewing data with the same coordinates may arise (because maybe make confusion for the user). This requires a new paradigm to overcome this conflict and to make it easier for users to analyze the data and make a decision.

The direct visualization paradigm enables visualization of objects that have the same coordinates (latitude and longitude), but can be discriminated by calculated their new virtual elevations in that space as an orthogonal line that links these objects is applied. This is the case, for example, in an archeological excavation, where a lot of objects found are assigned to the same geographical site, and they were found at same coordinates. The program rearranges the data in groups, and each group contains data objects which have the same longitude and latitude. The program displays the data in one unit vertically and the difference in distance between each artifact and the next is 10 meters according to the paradigm, we chose this distance after multiple attempts because we found this is the best distance to preserve the level of details.. (Figure 3.5 illustrates this process).

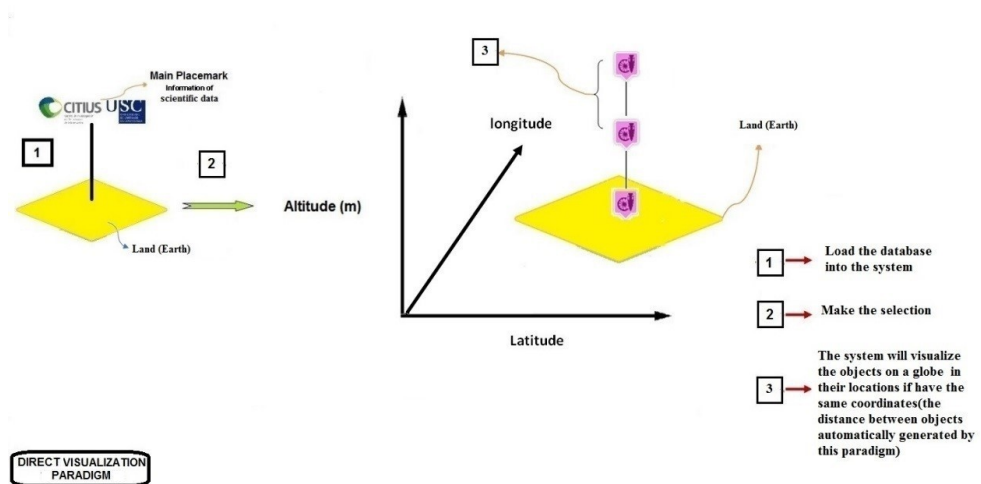


Figure 3.5: General diagram of direct visualization paradigm.

Time-Layers Visualization Paradigm

Sometimes the result of a query over a time series of data gives huge amounts of data (objects) in the same area, but with different chronology. This happens, for example, in archaeological data where different depositions are made at different times. This paradigm helps the user to discriminate the results visually, based on the time that they have associated as metadata.

In this paradigm, the system links the archaeological materials with the date they appeared in their sites. This solves the problem of representing pieces from the same archeological site that have been extracted in different deposition over time.

The aim of doing this is to enhance the representation of our visualization system by showing different time phases (levels). To do this, the user must select the target interval (in years) through the main interface. The system will automatically create a layer for each interval (see Figure 3.6).

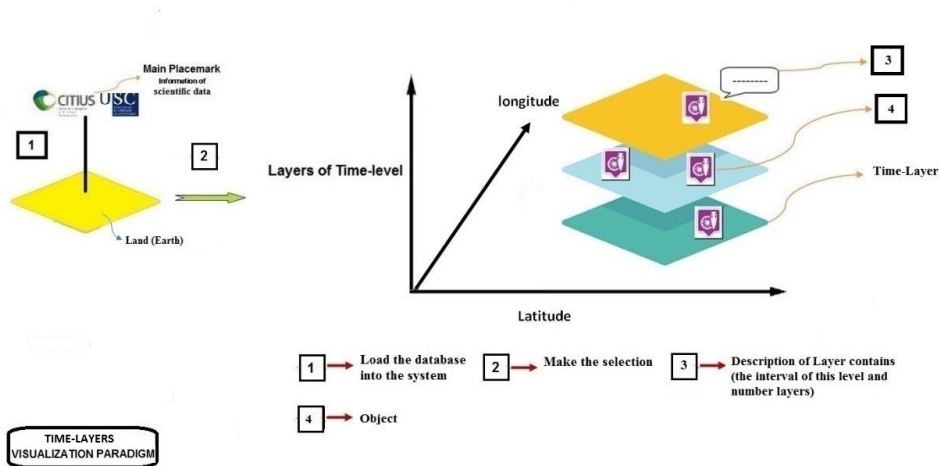


Figure 3.6: General diagram of Time-levels visualization paradigm.

Equalizing Number of Levels Visualization Paradigm

Sometimes there are too many objects that satisfy a query to be represented in the same location. One solution could be to distribute these objects uniformly in several layers according to their numerical or text properties. In this paradigm, the user selects the number of layers

he wants, and the algorithm associated with the paradigm calculates the intervals relevant for each layer, over the property selected, in such a way that all layers have the same number of elements. This process is shown in Figure 3.7.

This paradigm for visualizing data objects (artifacts) is based on user selection of the number of layers (levels) and the name of a feature in the dataset.

The data objects will be distributed in the layers equally and regularly, but in this paradigm, if the number of objects is not an exact multiple of the number of layers, then the last layer will contain a larger number of objects than the others.

In this case the system will work as follows: First, the number of added data objects will be clarified in the last layer description. Second, the icons of these added items will be changed to distinguish other items (see Figure 3.7).

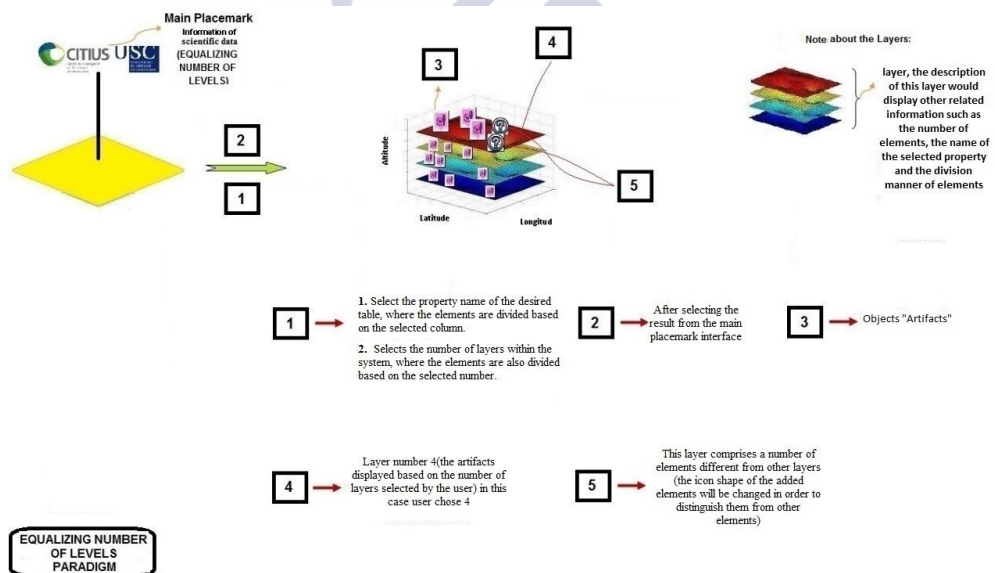


Figure 3.7: General diagram of Equalizing Number of Levels paradigm.

Equation of Level's Content Paradigm

When we work with the Time-Layers Visualization Paradigm, it can be difficult to know the periods stored in the database to creates the intervals required based on the number of

layers selected by users. The periods must be selected to fit with the number of different layers.

Based on that, we identified a need to create and divide periods dynamically, instead of using predetermined periods. In this paradigm, periods are determined automatically based on system equations.

The equation of level's content paradigm depends on the selection of the main placemark interface (the property name of the dataset and the number of layers) for visualizing data (Artifacts) and the way of dealing with it (see Figure 3.8).

In this paradigm, there are two cases based on the data type of the property the user chooses to establish the visualization. The first case is when the user chooses a property stored as a text. Here the system will deactivate the number of layers (list box) automatically, because the system will distribute the created layers based on the item names (without redundancy) according to the column which has been chosen. The second case is when the property is numeric. In this case, the system will distribute the data across intervals. The first interval starts with the lowest value of the property, and the last interval ends with the highest value. The number of intervals created is equal to the number of layers selected by the user, according to the following pseudo code:

Algorithm 1 PSEUDO CODE FOR EQUATION OF LEVELS CONTENTS PARADIGM

```

1: Input:
2: Attribute(x)           ▷ The Attribute array is the property name chosen by the user.
3: Number – of – Layers   ▷ The Number-of-Layers variable is the layers number (equal
                           with the number of intervals) choose by the user.
4: Output:
5: Set – Of – Intervals[]           ▷ Final array stored the values of intervals
6: Initialization:
7: Min                         ▷ Declare the variable called Min saved the minimum element
8: Max                         ▷ Declare the variable called Max saved the maximum element
9: Min ← Minimum-of(Attribute)   ▷ Store in the Min variable the minimum value of the
   Attribute array
10: Max ← Maximum-of(Attribute) ▷ Store in the Max variable the maximum value of the
   Attribute array
11: Difference ← (Max–Min)     ▷ Calculate the difference between maximum and minimum
12: Digit – No ← (Difference / Number-of-Layers)   ▷ Calculate the value of the Digit
   number as double data type
13: Calculate Intervals: ▷ start the procedure of set the minimums and maximums values
   of each interval
14: i ← 0                       ▷ set the value of i to 1 as a counter of the While loop
15: Temp ← Min                 ▷ Store the value of the minimum to the Temp variable as temporary
   storage
16: While (Number – of – Layers ≥ i) Do           ▷ While loop
17: Temp – Max ← Min+(Digit–No*i) ▷ Calculate and store the maximum of the i interval in
   the Temp–Max variable as temporary storage
18: Set – Of – Minimum[i – 1] ← Temp ▷ Store in the Set–Of–Minimum array the minimum
   values of each interval
19: Set – Of – Maximum[i – 1] ← Temp–Max   ▷ Store in the Set–Of–Maximum array the
   minimum values of each interval
20: Temp ← Temp–Max + 0.01           ▷ Set the minimum value in the next interval
21: i ← i + 1                       ▷ Counter
22: End While
23: For (j ← 0 To Number-of-Layers – 1) Do           ▷ For loop
24: Set – Of – Intervals[j * 2] ← Set–Of–Minimum[j]   ▷ Store the minimum array values as
   even elements to an array called Set–Of–Intervals
25: Set – Of – Intervals[(j * 2) + 1] ← Set–Of–Maximum[j]   ▷ Store the maximum array
   values as odd elements in array called Set–Of–Intervals
26: End For
27: Return Set–Of–Intervals []

```

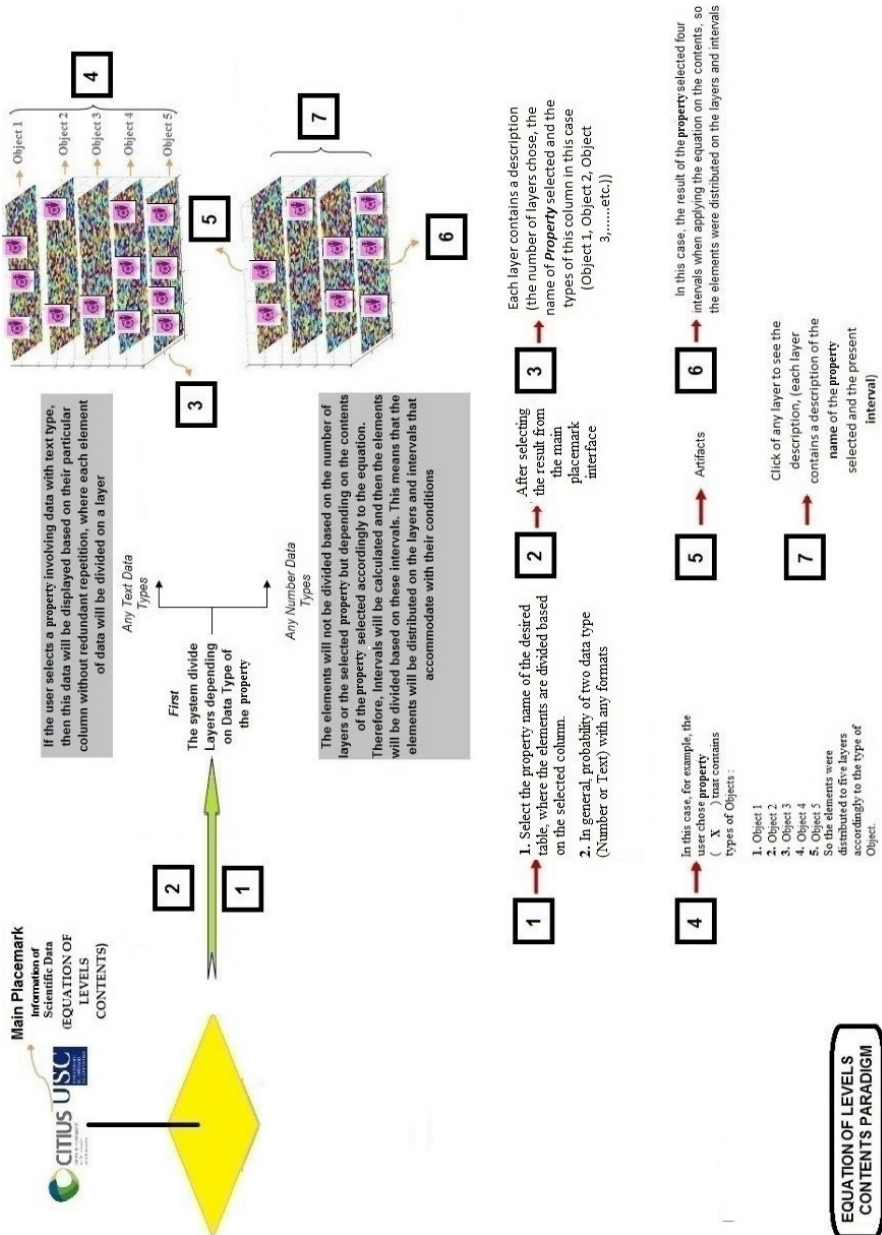


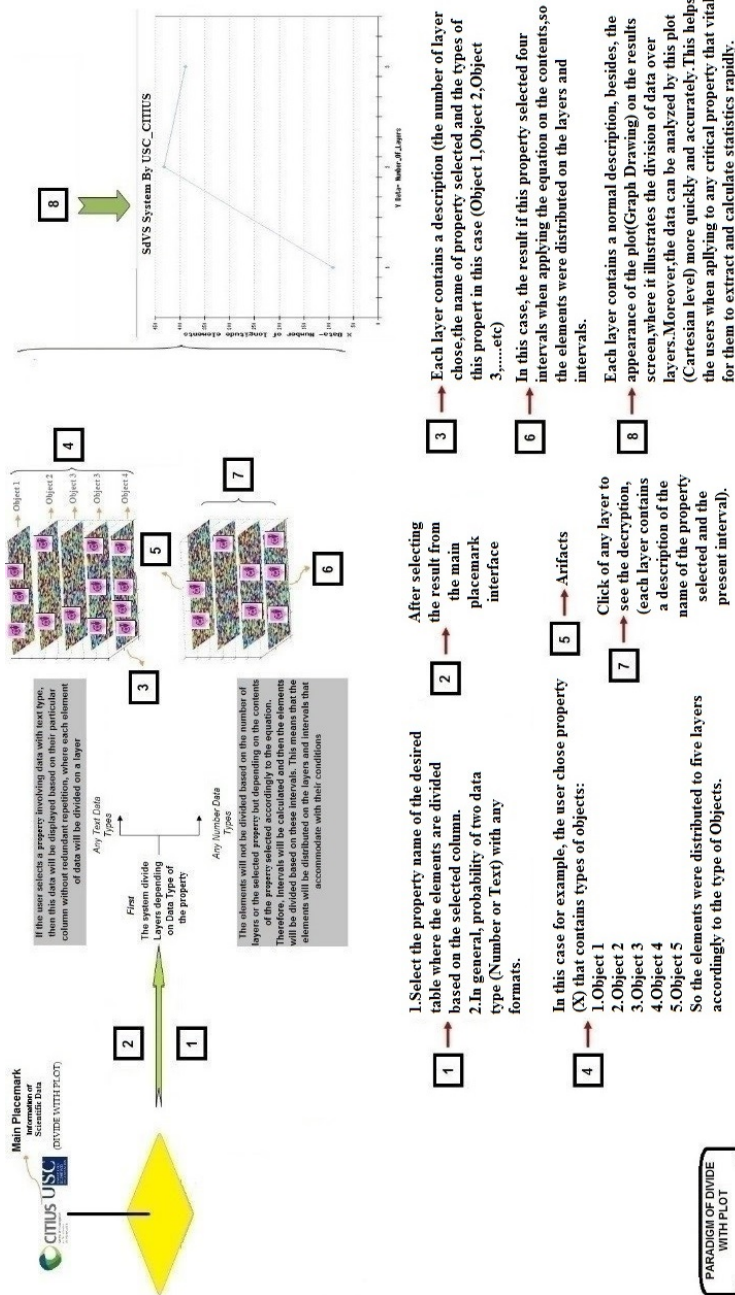
Figure 3.8: General diagram of Equation of Levels Contents paradigm.

Divide with Plot Paradigm

When applying the previous paradigm, there may be a need to make a graph containing the results and summarizing the details in a more natural way for the users. This paradigm was developed to meet that need.

The operation of this paradigm is similar to the previous model, but extends it by displaying a graph with some critical information including the descriptions for each created layer. The data can be shown in different ways depending on the graph type chosen by the user, as for example 2D, 3D, XYPlot, Bars, a histogram, pie chart, and line chart. (see Figure 3.9).





3.2.2 Human Computer Interaction Techniques

In this section we focus on the second contribution of SdVS, applying innovative techniques for Human Computer Interaction (HCI) to utilize the new visualization paradigms.

As mentioned earlier, recently Geographical Information Systems (GISs) have played an increasingly significant role in society. Not only have the abilities of GIS packages expanded, but their spectrum has been broadened by the generalization of software such as Google Earth, which has added new dimensions to navigation, while still using the same interaction method. We argue that conventional GIS interfaces limit productivity by not being intuitive enough to new users and by causing extra delay due to dispensable modality. As a step on the road to solving these problems, this thesis proposes new human interaction techniques, which have been applied in the CITIUS (Spain) and the Royal Jordanian geographic center (Jordan). These applications support our assumptions about the importance of these techniques for interactions in natural and easy ways.

SdVS contains multiple interaction techniques for GIS applications, which use a synergistic operation of several kinds of input devices in order to allow a natural interaction.

The information allows the different input devices to determine actions and commands for interaction with the software.

Furthermore, the integration between the sound, gestures, and mouse mechanisms provides another advantage of SdVS, because other systems are based on one mechanism.

SdVS also includes four techniques for Multidimensional Geodata Interaction using detection and tracking of human hands and recognition of human gestures and voice processes. Accordingly, the contribution of this system in the HCI context can be summarized as:

- Provide flexible input methods.
- Support high-performance control.
- Provide users with several options for new interaction techniques.
- Provide the ability to deal with a more significant number of environmental situations, tasks, and users.
- Allow adaptation to continuous changes in the environmental conditions such as the distance between the wall and Kinect and the projector resolution.
- Avoid use of only one interaction method throughout the long usage of a computer.

- Improve avoidance of errors in decision-making; e.g., when the user says a country name, the system can go directly to the location on the electronic map, without the need for the user to know the position.
- Support the use of simple and short words to enhance the accuracy of speech recognition and control processes.

The following subsections briefly describe the new techniques for human-computer interaction available by using SdVS. These summaries can be used for understanding how the interaction works. In the following chapters, we will explain these techniques in more detail by applying real scientific data.

CONTROL – GIS – PRIMARY (CGP)

In the CGP method, we use three different mechanisms: gestures, voice and finally mouse, with each of them integrated to do the work in this method.

Each of these mechanisms has a particular function. The mouse is responsible for control of the mouse pointer on a map. The voice is used to specify the names of cities or locations to which the user wants to go. Finally, gestures are used to control paths on the map view using the hands.

The most important characteristic of this method is that it is standard and easy to use. It also can be used for multiple devices. As we can show, Figure 3.10 presents a summary of how this technique works. We notice the system would wait to receive the correct gestures, and then interpret each gesture to specify the right action related to it.

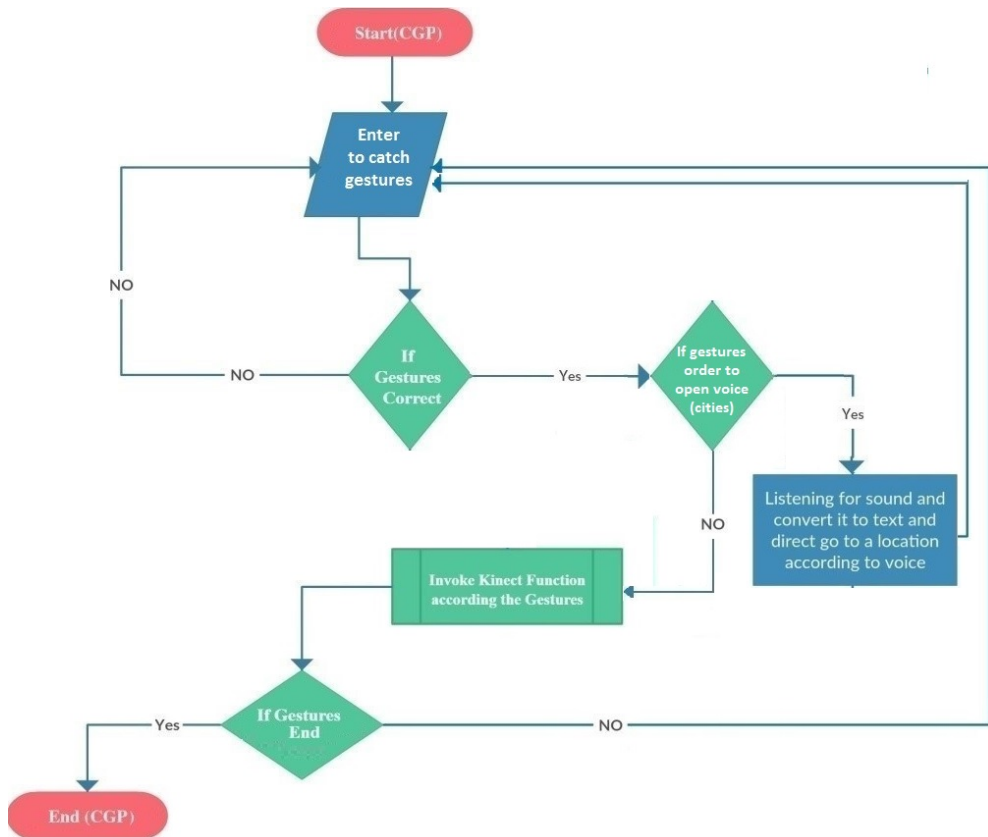


Figure 3.10: The Flowchart of the CGP Method.

VOICE CONTROL

VOICE CONTROL USING MULTIPLE DEVICES WITH GIS APPLICATIONS (VCMD)

Graphical interfaces for GIS typically require users to use complicated keyboard and mouse combinations. This can be a significant barrier and boring for new or occasional users. Even for experts, precise control of 3D maps can be challenging. To help address these challenges, we developed the VCMD technique to support multiple consumer voice recognition devices. This technique allows intuitive control, as if users are directly manipulating 3D objects and navigation through sounds.

We can summarize the benefits of the VCMD through its support of simpler and shorter speech words (thus enhancing the accuracy of speech recognition), and ability to handle a more substantial number of environmental situations, tasks, and users.

As we mentioned, different types of voice recognition devices can be used by this method for control by voice, such as microphones, including individual or standard Kinect microphones. This method aims to help disabled people to browse in different GIS systems, as far as we have parsed the standard navigation orders to the specific commands in each one (NASA WorldWind, Google Earth, Yahoo Maps). Therefore, they can do browsing in an effective way and with minimal effort.

Consequently, VCMD is primarily based on the use of voice control so that we can move to any city by vocalizing its name. In addition, we can control all directions through sound, which makes this method helpful for disabled people.

In Figure 3.11 we show the flowchart that clarifies the general mechanism of VCMD. In summary, note the first thing the system will do is wait for input voice keywords; after that it will invoke the function according to the keyword.

This method, however, is not able to select any object presented on the map, because the GIS applications do not allow external programs based on voice exploitation to reach any object on the map. Therefore, voice control using motion sensing input devices and location (VCMDL) method has been developed to overcome the weakness of voice control using multiple devices with GIS applications (VCMD).

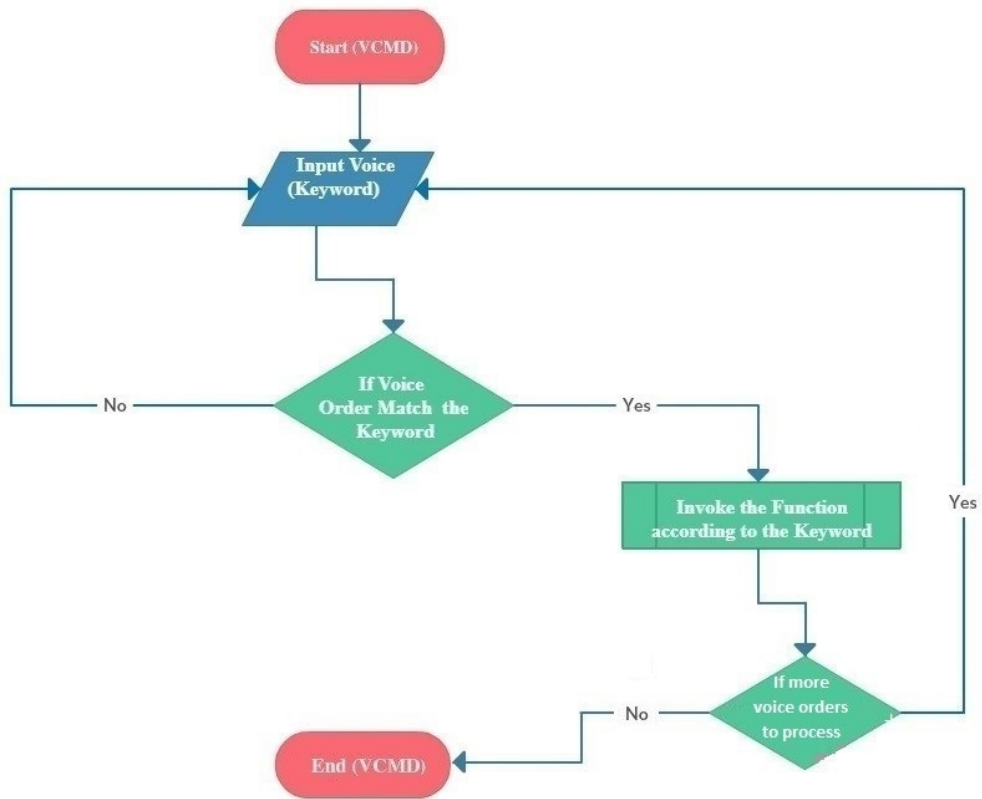


Figure 3.11: The Flowchart of the VCMD Method.

VOICE CONTROL USING MOTION SENSING INPUT DEVICES AND LOCATION (VCMDL)

The VCMD method, as noted, does not allow the user to choose or activate anything on the map. The VCMDL method has been developed to overcome this problem.

Figure 3.12 explains the operation of the VCMDL method. We can see from this figure that the method is complex, so creating and implementing the code for this method is not easy, but after finishing and applying this technique, user feedback appears to show success because VCMDL combines the mouse with voice and gestures; in addition, the user can search via sound and vocalization (by the name of the location).

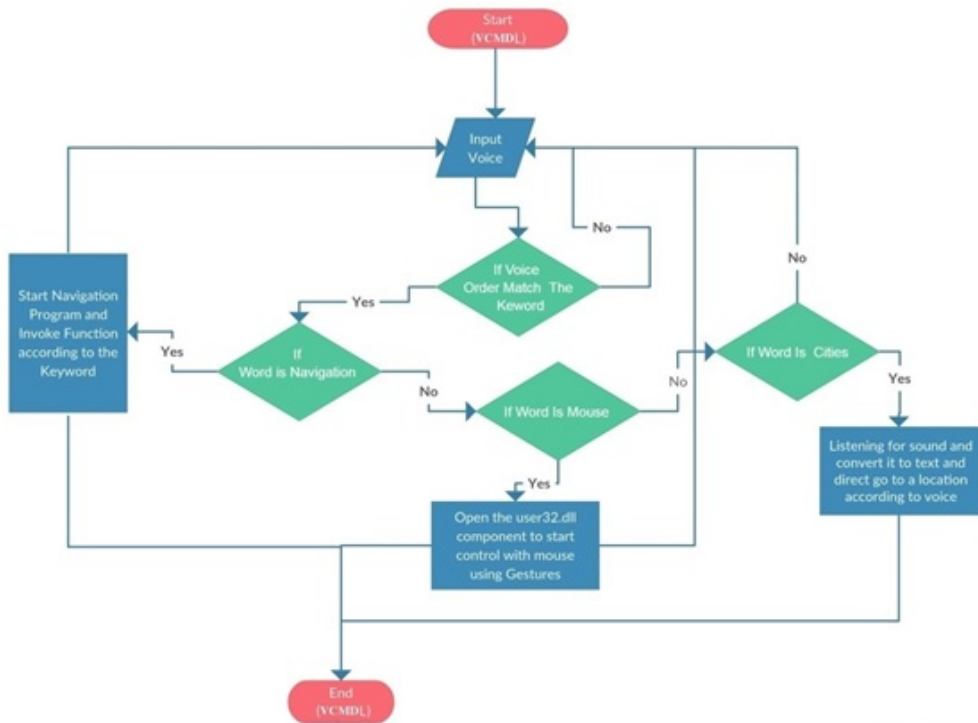


Figure 3.12: The Flowchart of the VCMDL Method.

CITIUS_SMART BOARD FOR GIS APPLICATIONS (CITIUS_GIS)

A need was further identified to develop a new dynamic technique (CITIUS_GIS) that is applicable not only to geographic information systems, but for any programs and domains such as archaeological, educational, health programs, etc., which can adapt to the continuous variations within the environmental conditions and is also scalable. On the other hand, this method depends on using the two basics devices:

- The Projector, where using to display the maps on the wall.
- The motion sensing input device, where using an interpreter of the gestures to control the map displayed on the wall.

When starting this method, the system will open the calibration form to set the points. After this the system will calculate the pixel values and distance between the display wall and

the motion sensing input device. When this step succeeds the system will display the hide top menu which has the buttons to control the GIS programs. If the user selected any of these buttons such as zoom in, zoom out, exit application, recalibration, left click, then the system will invoke the motion sensing input device function according to the button chosen. If the reset button is chosen, the system will recall the calibration form again. Finally, if the user chooses the exit application button, the system will terminate the application.

Figure 3.13 shows the operation of the CITIUS_GIS method.



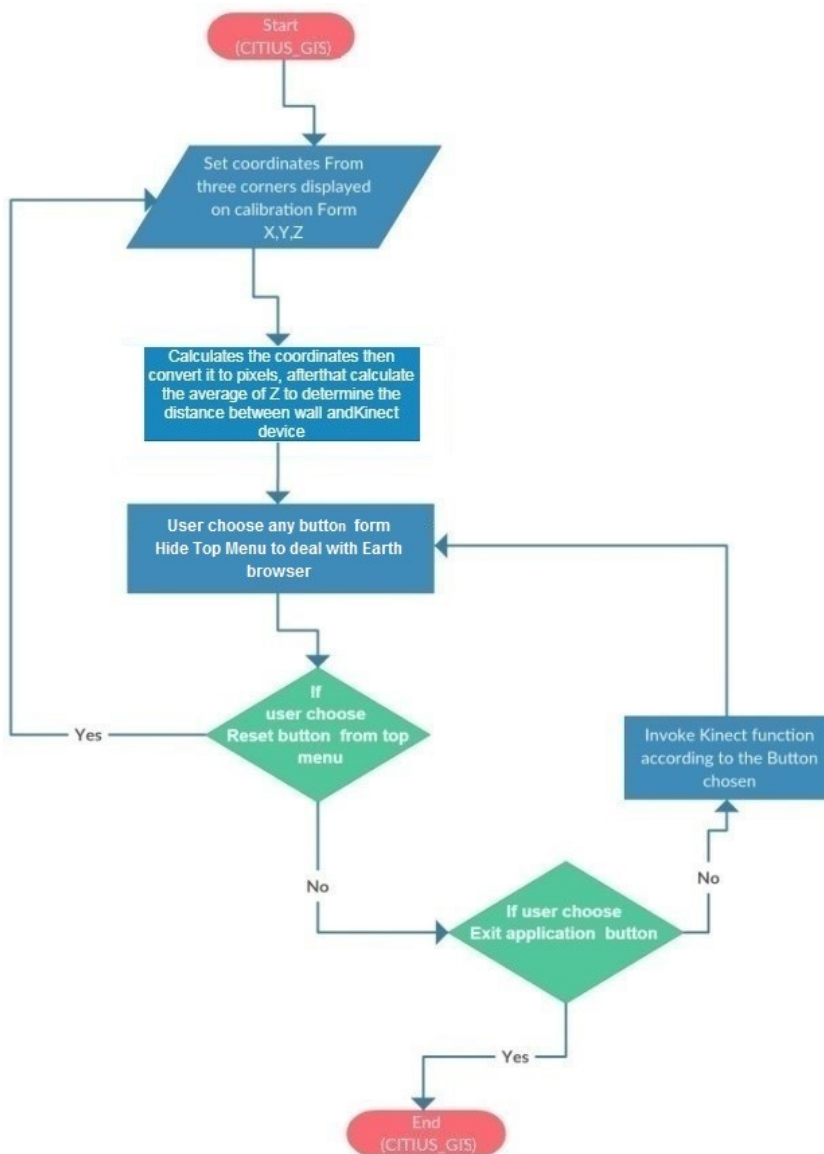


Figure 3.13: The Flowchart of the CITIUS_GIS Method.

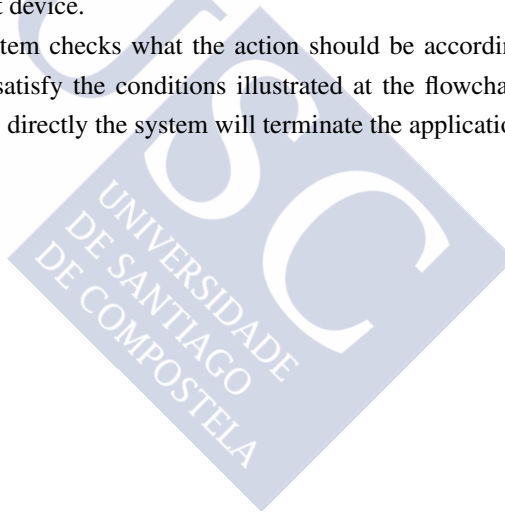
CITIUS SMART BOARD WITH VOICE FOR GIS APPLICATIONS (CITIUS _ SBV)

The use of voice in human-computer interaction techniques is one of the most important methods.

The voice is considered an efficient input modality because it allows users to give commands quickly to the system, and effective natural language processing bypasses the need for complicated navigation menus, at least for everyday tasks and known commands. Therefore, we developed the CITIUS Smart Board with Voice for GIS Applications technique.

We can see a diagram of the sequence and actions for this CITIUS _ SBV technique in Figure 3.14. The first step in this method is opening the calibration form to set the points. After this the program will calculate the pixel values and distance between the display wall and the motion sensing input device.

In the next step, the system checks what the action should be according to the correct keyword input. Again we satisfy the conditions illustrated at the flowchart such as if the keyword is (exit application) directly the system will terminate the application and so on.



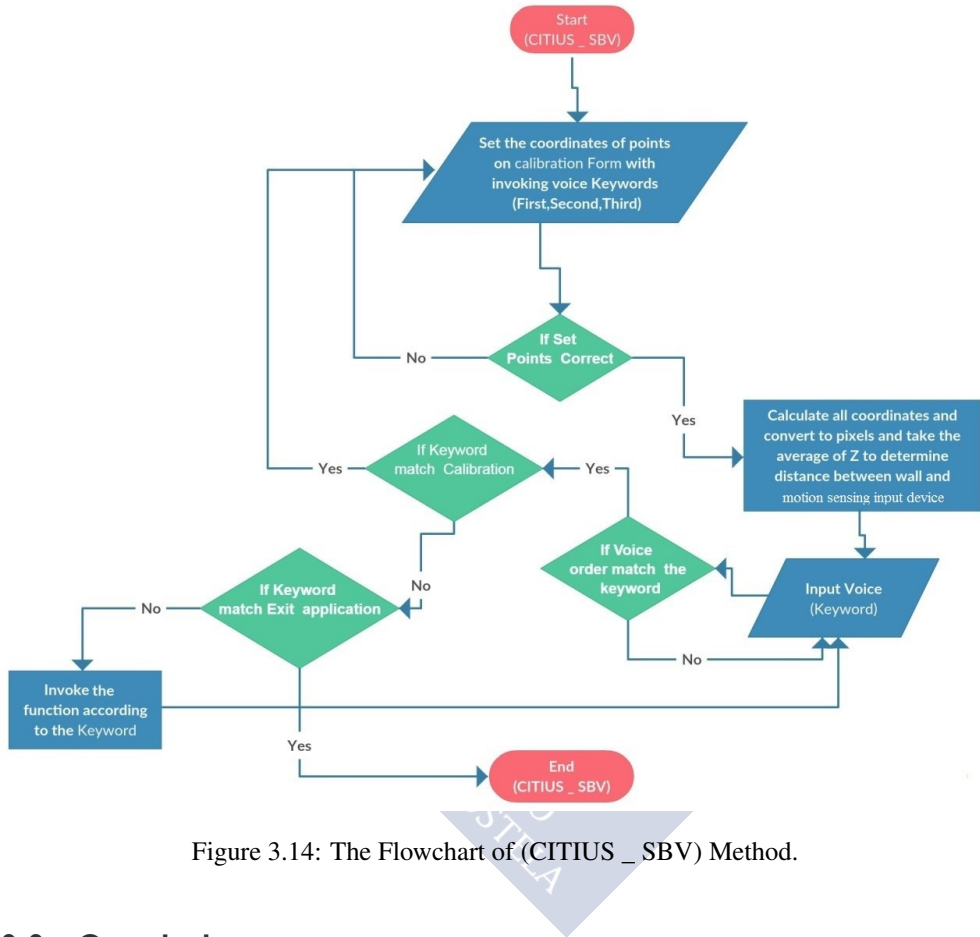


Figure 3.14: The Flowchart of (CITIUS _ SBV) Method.

3.3 Conclusion

The development of Computer Science has greatly influenced visualization systems, allowing the introduction of new paradigms of cartography, in which computing tools have been added to the process of visualizing geographical information.

The Scientific data Visualization System (SdVS) is one of these new systems. The SdVS provides the possibility of using a multimodal and multidimensional geodata interaction and visualization framework, enabling expansion of the role of maps and systems as tools for the understanding of spatial phenomena.

In summary, in this chapter, we proposed the Science Data Visualization System SdVS that supports several different methods for visualizing and interacting with geodata, in order to dissemination knowledge about geodata using various GIS applications.

Furthermore, SdVS provides guidelines for developing other visualizing and interacting applications in the future, and for ways that users can use SdVS systems to enhance the understanding of the past, present, and future through the use and documentation of scientific geodata such as historical/archaeological interpretations.





CHAPTER 4

VISUALIZATION PARADIGMS OF (ArVS)

4.1 Introduction

This chapter describes the archeological visualization system (ArVS) which we have developed to meet the requirements of visualization described in the introduction. As mentioned before, this ArVS is an application framework targeted at scientists and archeologists (expert or non-expert users). ArVS as a framework is composed of a set of interaction techniques that allow users to retrieve data from a database, and their visual representation. In order to develop and to test a system that satisfies the requirements described previously, we have chosen the archeology context. This context will allow us to demonstrate that the proposed paradigms for interaction and visualization, when we manage a huge quantity of data, are useful. In this chapter, we will explain the structure of the archaeological visualization system (ArVS) and how the data flow processes were applied.

4.2 Archaeological Data

Spatial data are defined by the information that determines properties and the manner of distribution of objects on the earth's surface [109]. Thus, spatial data represents all information regarding geographic features, including relationships between data and the shape and location of data [110, 111]. Although archeological spatial data may be distributed on different scales, the archeological domain achieves an optimal dealing with enormous volumes of spatial data. The volume of spatial data involved in the archaeology domain may range

from a small amount for various artifacts to an enormous amount representing a continental landmass [112].

The data used as a case study within the current work represents the archaeological diggings conducted in the Rocha Fort Castle, which is a popular historic site in the Galicia-Spain region. The castle was constructed within the twelfth century, and it was damaged in the fifteenth century. The Archeological Project to Appreciate, Recover and Study the Rocha Forte fortress represents an example of the excavations performed on the site. On the other hand, this project was coordinated and instigated by 'Santiago de Compostela City Council', and funded through the Spain Ministry of Sports, Culture and Education [113].

Of course, the system can be applied to any other archaeological data, or in another different domain, as our system is dynamic and scalable. This is another advantage of ArVS.

The work aims to study the archaeological evidence within the gathered data, and then to visualize the environment of this data, using a system developed by authors. A suitable information system has been designed to achieve these goals.

Figures (4.1 and 4.2) represents the data model required for this research. The data model has been designed in a modular manner, which combines different aspects in a shared logic work.

The data model that collects archaeological information is based on four basic units: the archaeological site, the interventions, the context and the archaeological evidence. These are our four principal entities.

The archaeological site is all space in which we identify some type of human activity. It is the entity on which the whole system is based and is characterized by responding basically to one or several cultural periods and one or several functional typologies. The set of archaeological sites is collected within the table **lv_sites**. Each archaeological site is uniquely identified by the primary key [idsite]. In addition, a string field [name] is included, which collects the common name of each of the sites. This name can be repeated in more than one site, as different sites with the same name are known.

The chrono-cultural characterization of each of the sites is carried out through the combination of two independent and controlled entities represented by the **cl_crono** and **cl_site_tip** tables. The first of them stores a sequence of general chronological periods, which allows each of the archaeological sites to be framed within a specific culture. The table of typologies of sites gathers the different functionalities that each site can have, in this way we can identify a castle, a city or any other type of dwelling place, economic activity or ritual, to give some

examples. The two previous tables are composed of a primary key ([idcrono], [idsitetip]), which identifies each record, as well as a string field that stores the name of each type or chronology.

As we have already mentioned, the chrono-cultural characterization has to be done by combining the two previous entities, so that we can recognize for example a medieval castle, or a Roman mine. But in addition, within the same archaeological site we can find different cultural periods and functionalities, which obliges us to create an intermediate table to represent this relation, where all the possible combinations registered within the same site are collected, whether because they have more than one functionality or typology in the same cultural period; or because they have a temporary survival in more than one historical epoch. These combinations are collected within the **u_site_crono_type** table, which stores as foreign keys the primary keys of the tables of sites, chronologies and typologies.

Actions are carried out at archaeological sites that provide data on various aspects. These actions are called interventions and are stored in the **lv_interventions** table. Interventions can be of very different types, which can be grouped into two large blocks: field and laboratory. In this way, we can include archaeological excavations or a bibliographic review, as either of the two sources provides data that are integrated into the general knowledge model of the same site. Each intervention has an identifier as its primary key [idintervention], as well as a name that allows it to be recognised.

Each intervention can be carried out according to its characteristics, in one or more sites. For example, in the case of field interventions such as an archaeological excavation, it is most often carried out on a single site. However, when a documentary source is emptied, it may collect data from more than one site, forcing us to create a table that allows us to relate both the interventions and the sites to which it refers. For the documentation of this fact, the **u_site_inter** table is created, which stores the combinations of interventions and sites with which each one of them is related. The primary keys of the tables of sites and interventions are collected as foreign keys.

Each intervention generates a register that documents and identifies both the archaeological evidence collected and the contexts and processes that have intervened in its formation and conservation to this day. This record serves to locate each piece of evidence spatially, be it a piece of ceramic material, a coin, or a sample of soil or coal that can be subjected to different analyses. The register also contextualizes this evidence within a specific Stratigraphic Unit

(SU). Stratigraphic Units are the evidences that a certain activity leaves in a specific space. These evidences can be human or not.

The documentation of this record creates the **lv_registry** table that is composed of a primary key that identifies each one of the documented evidences [idregister], besides using as foreign key, the primary key of the **u_site_inter** table; which allows us to identify which site and intervention it belongs to. It is common to associate the concept of record to that of "Bag". This is because in an excavation, evidence collected in the same position or context is placed in a bag as a container.

The contexts that are identified within an intervention are associated with different SU. These are collected within the **lv_ues** table, and have a primary key associated with them. This primary key is used as a foreign key within the **lv_registry** table to identify the context of each of the items in the record.

Finally, the model also includes a structure that allows us to identify and analyze archaeological evidence. Within this group we include those man-made artifacts, but also a series of other evidences such as the so-called ecofacts, which are organic and inorganic remains that have not been elaborated by man, but that can provide information about human activity in the past. The heterogeneity of this group of evidences is very great, for what different structures have been created that allow the documentation and the study of each one of these types, for example for ceramic materials, numismatic or anthracological remains.

The general scheme of how archaeological evidence is documented is based on two fundamental entities that have two associated tables: **lv_inventory** and **lv_objects**. The **lv_inventory** table stores each of the individual evidences that are contextualized within the same record. In this way, we have a primary key that allows us to identify them [idinventory], as well as the foreign key [idregister] that allows us to relate it to the record it belongs to. In its structure we also have an identifier that is generated within the interventions themselves [inventorynumber], and that is an inventory number with a functionality merely identifying.

Archaeological evidence can be grouped into a larger entity, objects. Frequently, the evidence collected is fragments of objects which, after laboratory work, cannot be reconstructed. In archaeological work the object is the entity of study and allows us to provide information to the site. In this way, each object can be composed of one or more fragments; as an example, if several ceramic fragments are collected from the same vessel, we would be interested in grouping them into a single object for study purposes. For the documentation of this reality, we use the **lv_objects** table that collects each of the objects with a primary key that identifies

them [idobject]. This key is used in the inventory table (lv_inventory) as a foreign key to associate each of the fragments to one of the objects.

Each object at the same time generates an associated documentation such as photographs, documents in text format, videos, ... In this case, only photographs of each of the documented objects have been collected. For the storage of this information the table **lv_images** has been created, where each image has as primary key the field [idimage], with a name of the photograph [name] and as foreign key the field [idobject], that allows to relate it with the object to which it belongs.

Further, the development of the model involved many particular themes that will be gradually integrated based on the demands. The model layout is centered on recovered field evidences, registrations, interventions, deposits and basic units.

By GIS logic, the system elements became independent information layers, since this logic has the ability to insert these elements in a common environment and real coordinates. Therefore, the system accuracy varies according to the elements of the GIS system.

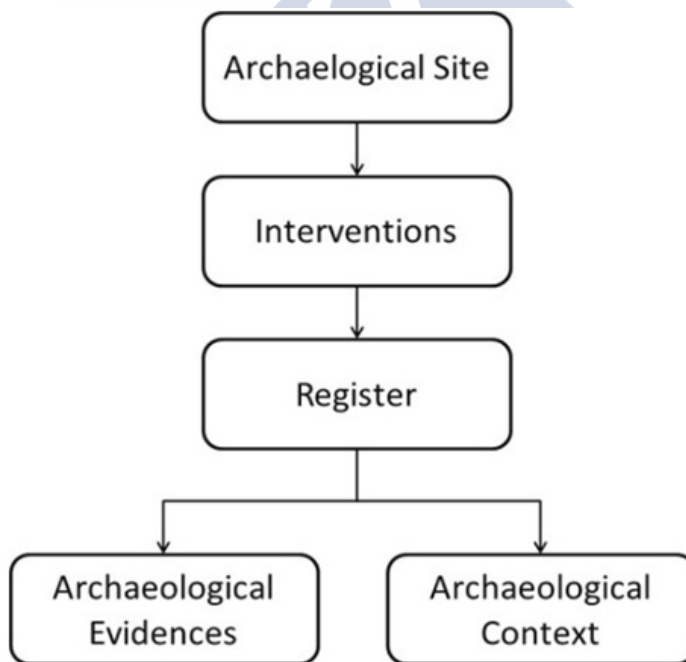


Figure 4.1: Basic structure of system data mode.

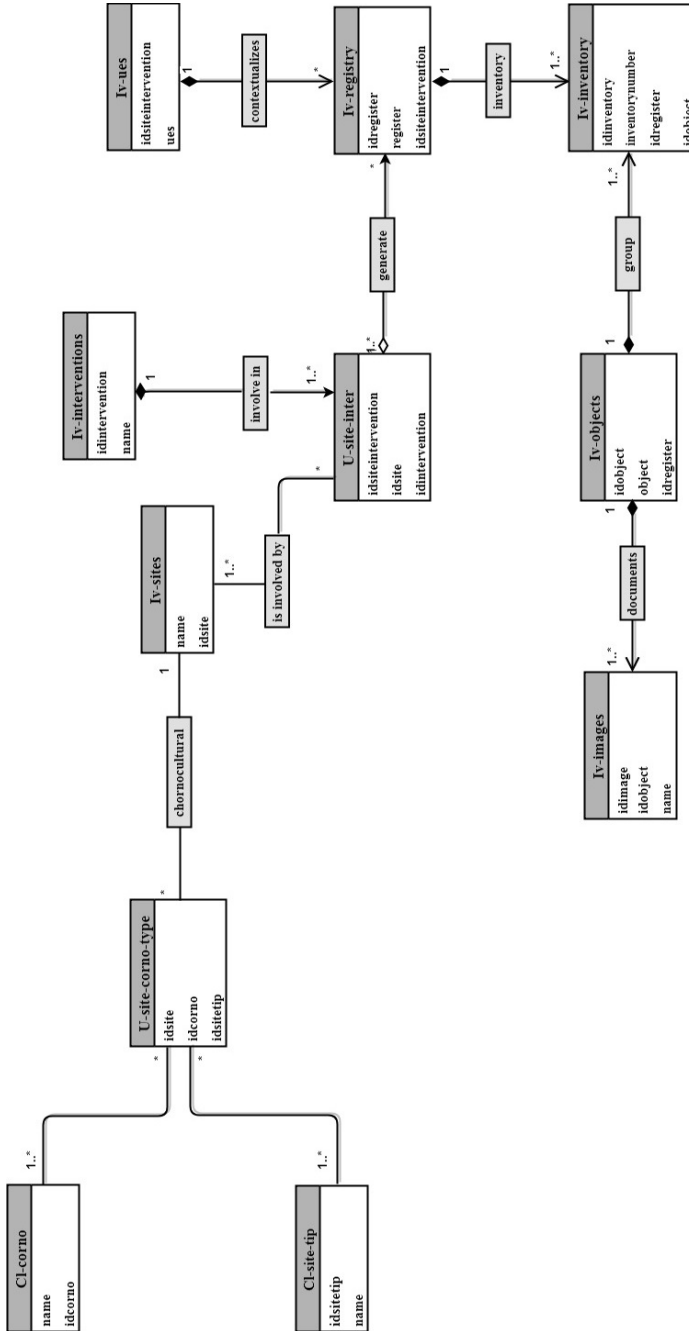


Figure 4.2: The system data model.

4.3 Architecture of The System

Virtual Globes (VGs) are rapidly becoming the new paradigm in the Earth Sciences for education and outreach, logistics, and data access. VGs such as NASA WorldWind, Google Earth, MSN Virtual Earth 3D, and several others are changing how science professionals and the public view and access geographic data [114].

According to Van Asperen et al. [16] and Yu et al. [115], Google Earth proves technically superior to others (NASA's World Wind and MSN Virtual Earth 3D) when examining their performance in disseminating geo-information to the general public through the Open Geospatial Consortium (OGC), as WMS for example. In addition, over the last decade, the impact of using Google Earth on various domains in GIS studies has emerged as an important frontier of research such as [107, 116, 117, 118, 119, 120, 121]. In addition, it maintained this superiority over other programs throughout this period. We select Google Earth among others (e.g., NASA WorldWind, MSN Virtual Earth 3D, etc.) as a framework of our study, because as Patterson argues in [17], it has many advantages, including but not limited to the following:

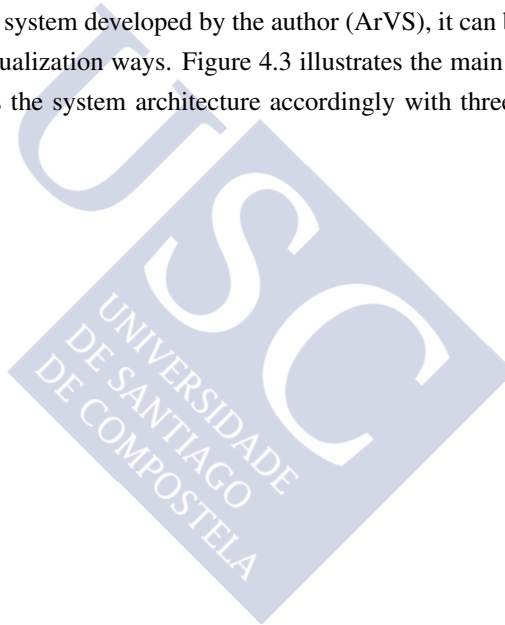
- It is a free licensing platform (economical-benefits).
- Maps and data may be updated with real-time information feedbacks.
- Utilize the terrain feature of Google Earth to appreciate the physical nature of the place.
- Public participation and collaboration is encouraged, by creating and downloading KML files.
- It supports a variety of data layers that may include supplementary readings and supporting photos and videos.

The architecture of Google Earth depends on using the layers feature to superimpose details of concern. This feature provides the base imagery layers (e.g., Borders, Roads, Terrain, Populated Places, etc.) and a variety of optional layers for features and conditions such as current weather, forecasts, traffic patterns and places of interest.

Based on the above, Google Earth has been used in this thesis as a visualization framework to develop a novel dynamic system for visualizing georeferenced data. Therefore, developing

a dynamic visualization system dealing with dynamic and huge datasets is the main contribution of this thesis, which also aims to enhance the interactivity of the system. Using this system, the required data can be extracted, analyzed and then delivered to the archaeologists.

The system database has been provided by the Galician Supercomputing Center (CESGA). Besides that, the data excavated from Rocha Forte Castle can be reached through web services provided by the SDI of CESGA. The VGE field will be enhanced by this system, which represents a novel tool to analyze and study the problems regarding the geographical environment in addition to improving the cutting-edge problem, which impacts the system interactivity. Besides the simplicity of the system developed by the author (ArVS), it can be applied by the archaeologists in various visualization ways. Figure 4.3 illustrates the main processing steps in this system and describes the system architecture accordingly with three Layers (Client, Application, and Data).



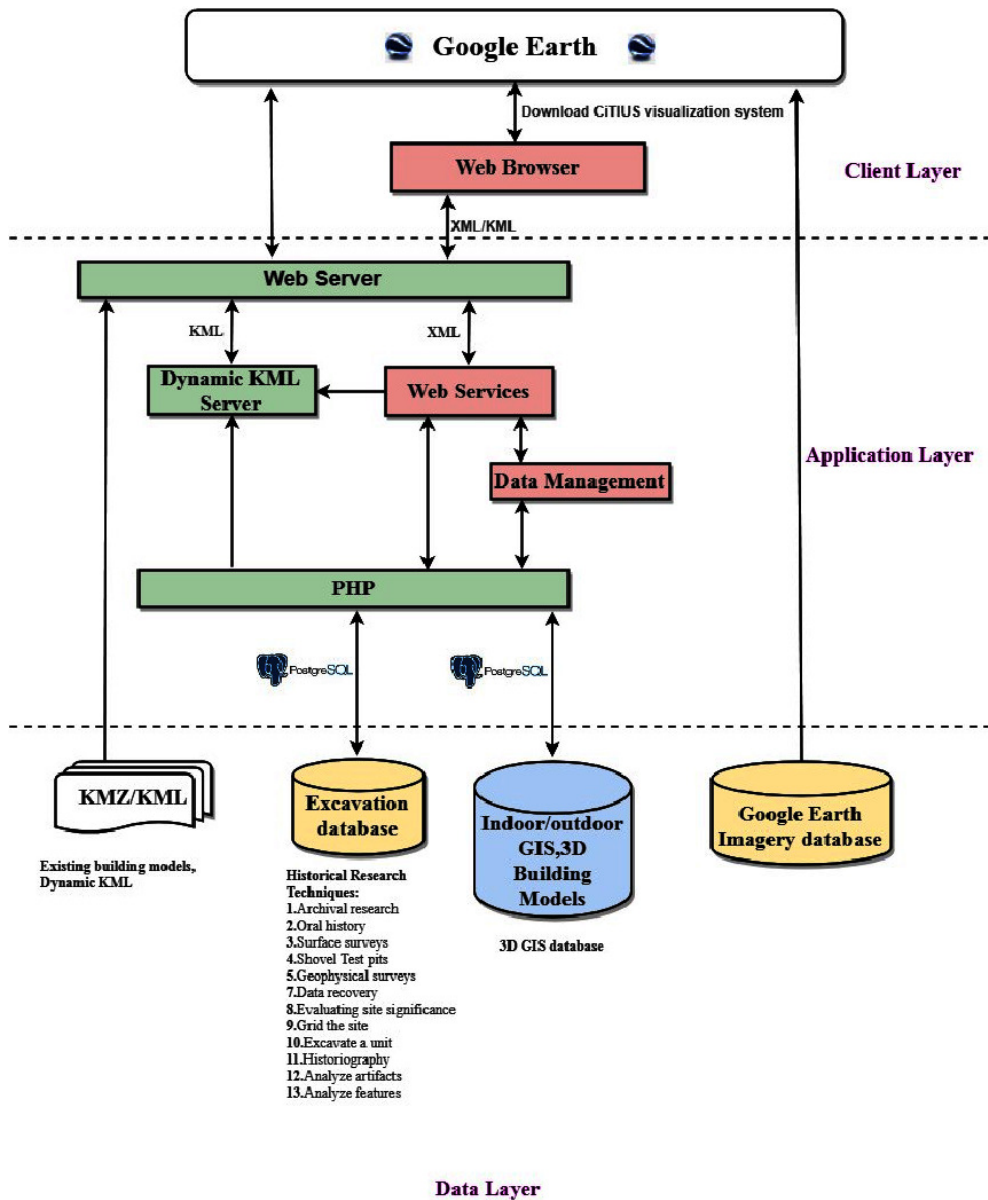


Figure 4.3: Architecture of the archaeological visualization system (ArVS).

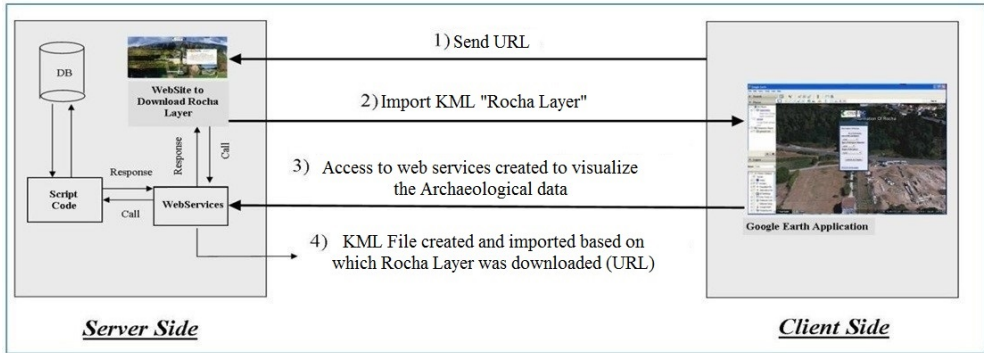


Figure 4.4: Data flow of the system.

A schematic of data flow in the system developed by the authors is illustrated in Figure 4.4. As shown: (1) the user first sends a request to download the Rocha primary layer (The Main Layer) from the website. (2) Then, the server of the website sends the answer, which involves the major placemark. This answer is sent in a KML file, which will be imported into the application of Google Earth within the client side in an automatic way. (3) After that, the user should interact with the primary interface (The Main Dynamic Interface) within the placemark description to show the results of visualization by access the web services provided to visualize the archeological data. (4) Finally, the results will be created and imported to the google earth application as a kml file.

On the other hand, the most important requirement for applying this system is to install the Google Earth application. This is a novel approach where a user does not need any extra condition, except just to install the Main Layer from the System (see Figure 4.4), and then instantly connecting and visualizing any information wanted directly from the web services created by Authors.

4.4 Visualization Paradigms

Information Visualization is a very important domain. In terms of representing the data in an efficient way, the integrated and interactive visualization tool developed by the authors aids the users and archaeologists to explore, present, collaborate and communicate visually large information spaces by applying novel and dynamic paradigms. This tool has been used in Jordan and Spain, with support and coordination with the Research Center in Information Tech-

nologies (CiTIUS) at Santiago de Compostela University, and Jordanian Royal Geographical Center, to expand knowledge in a way that has not been applied before.

Six different visualization paradigms can be downloaded by the client from our system in order to effectively represent the data: Time-levels Visualization, Sub-placemark Dialogue Visualization, Direct Visualization, Equalizing Number of Levels, Equation of Levels Contents and Divide with Plot (see Figure 4.5).

VISUALIZATION PARADIGMS

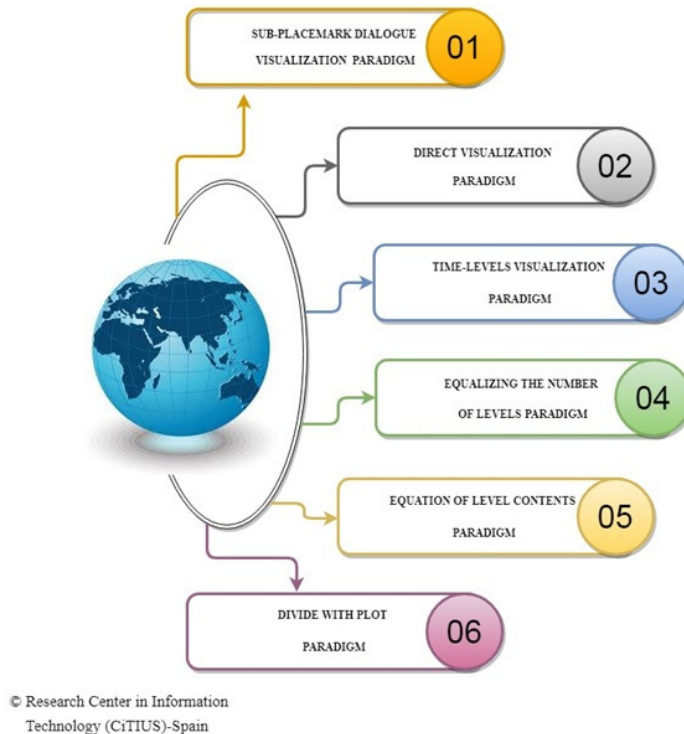


Figure 4.5: Visualization Paradigms.

4.4.1 Paradigm of Sub-Placemark Dialogue Visualization

In the sub-placemark dialog visualization paradigm, a web service is called by a script code. Where the web service added to GUI (such as an executable program or web page) to offer specific visualize functionality to users. After that, we are using the Representational State Transfer (REST) for creating web services to provide interoperability between computer systems on the Internet. This web service created to simplify linking to the database and the converting process to KML format by creating an XML file. Then the main interface (included in the placemark description) is created by this paradigm to effectively display data see Figure 4.7(a). This interface has the ability to dynamically fetch the required data from the database. Hence, the interface contents are changed directly by the modification of the database. After that, the user can select the data required for visualization by a collection of filters, dynamically created as a function of the properties of the objects selected for visualization. The data are directly delivered to the system, which reads this data from the database and categorizes it into independent groups. Finally, the system forms sub-placemarks to describe and store the dialogues of categorized data as well as their coordinates. The user can use the new dialogue along with the results of the primary dialogue to choose any data needed for paradigm visualization instead of performing a search on the overall database. The advantages of this paradigm are:

- Ability to adjust the data accuracy to fit within a certain Level of Detail (LOD) through the reduction of 3D-object representation complexity.
- Ability to optimize the way that data has been retrieved in the first step to achieve optimal recovery and interpolation of data, or continuous visualization, because this paradigm depends on the main dialog results when searched.
- Ability to represent multiple objects at the same coordinates to provide the user with clear sight.
- Ability to deal with constructed layers without any overlapping between them, since the mechanism of this paradigm separates the layers by displaying them above others.

A dynamic interface has been developed as shown in Figure 4.6(b) and Figure 4.7(a); the interface provides the user with a description of the placemark. The description allows the users to effectively react with the interface and helps to generate the results of visualization in a simpler way. Figure 4.7(a) illustrates that the client should press the “Submit and Display”

button within the interface to categorize any data for visualization. By this action, a request will be sent to the web service to transform the data into the format of a KML file in order to import it as a layer within Google Earth. This operation is visually explained in 4.7(b).

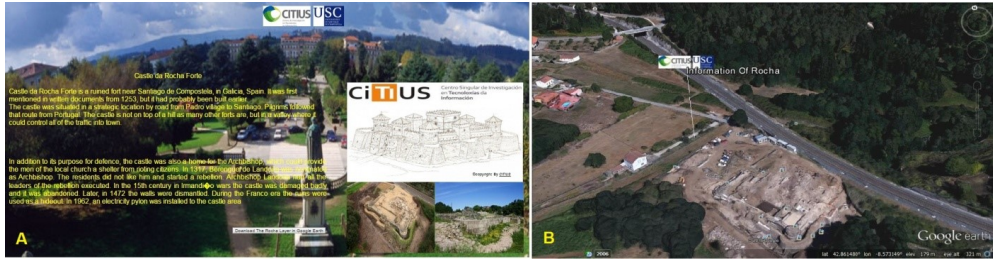


Figure 4.6: a) Downloading Rocha layer from the website. b) The primary placemark.

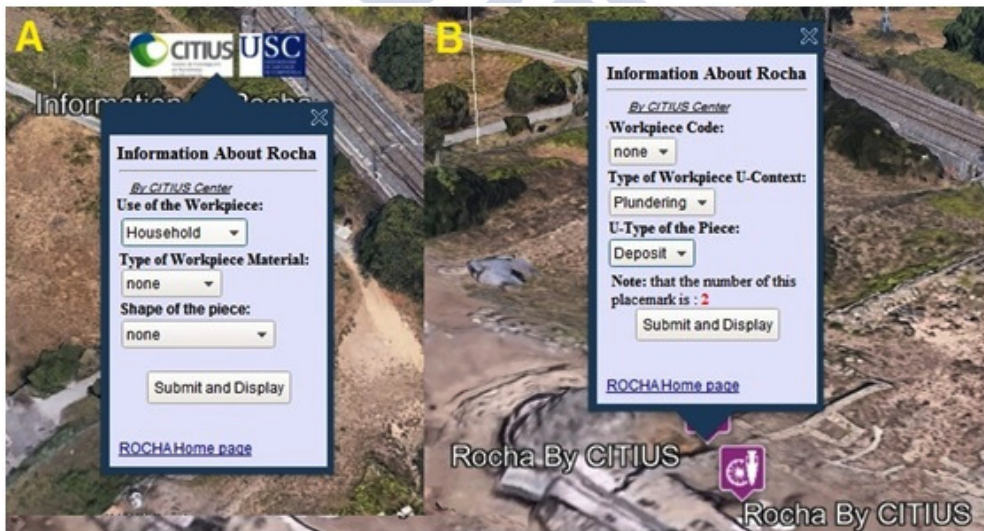


Figure 4.7: a) The primary interface. b) Sub-placemark.

As shown in Figure 4.7 (b), a KML file is created after choosing the data from the main layer that contains the sub-placemarks only when the distinct coordinates satisfy the condition of the main layer. As an example, the figure describes only two sub-placemarks that satisfy the condition (one of them is hidden under the main menu in Figure 4.7 (b)). Hence, for the same coordinates that have been checked, it only creates the first sub-placemark, where

any other new sub-placemark for the same coordinates will be included, without the need to create new sub-placemarks. The counter will adjust this step by automatically adding new sub-placemarks. Figure 4.8 illustrates the sub-placemark icon size, where it is elastic (flexible) and directly proportional to the number of elements in the same coordinates. To enhance the system performance and to reduce the time of fetch, only the nested placemarks elements that verify the sub-placemark conditions are authorized to appear in the same coordinate. Rather than searching all the elements within different coordinates and to avoid the overlap of layers, the new elements (Layer) are introduced in an altitude shape as shown in Figure 4.9 (a). By selecting the targeted element, the user can retrieve the information (metadata) that these elements hold in one and two dimensions. Figure 4.9 (b) illustrates an example of the previous case, where a 2D image and associated metadata of an archeologic piece is shown at the same position where it was found at the ground.

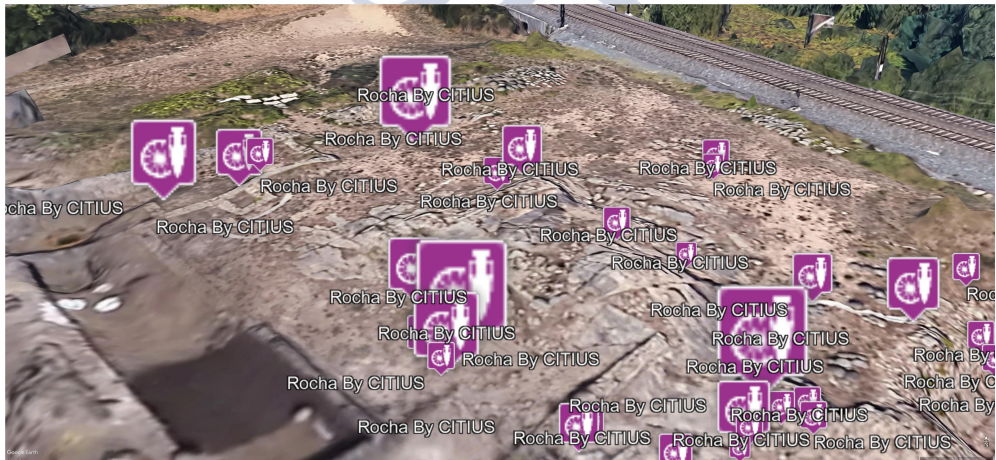


Figure 4.8: Icon to modify sub-placemark.

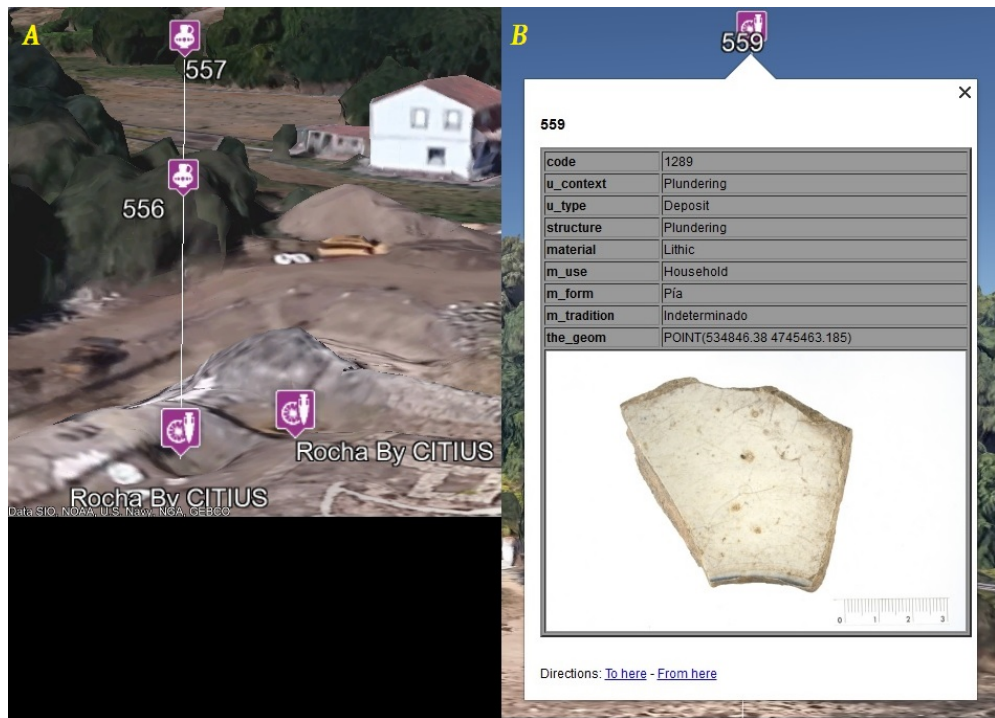


Figure 4.9: a) Nested placemark. b) Element information.

4.4.2 Paradigm of Direct Visualization

Large numbers of archeological pieces are located at the identical coordinates within archeological excavations. The direct visualization paradigm can be used to solve this problem by modifying the altitude based on objects and elements presented within the identical coordinate.

Indeed, the representation of elements that are on the identical coordinate is one of the major drawbacks of Google Earth, where this issue can negatively impact the user decision to select the appropriate elements for visualization. The complexity of this issue increases with increasing numbers of elements that demand representation. An instance of this problem is shown in Figure 4.10 (a), where two elements are located at identical coordinates: elements “145+146” and elements “547+548”. The solution of altitude-based shape has been applied

to overcome this problem. A vertical line has been used to join together the elements that share identical coordinates, as illustrated in Figure 4.10 (b).



Figure 4.10: a) Example of two objects that existed in the identical coordinate b) Applying direct visualization paradigm.

4.4.3 Paradigm of Time-Levels Visualization

This type of paradigm is used to associate archeological materials and their dates with the archeological contexts in which they were deposited. The aim is to solve the problem of the representation of the different pieces that have been recovered in the same site, but which have been obtained over time from excavations. This paradigm also helps to improve the representation of the visualization system in several time intervals. The user can invoke this paradigm by selecting the required time interval in years through the primary dialogue. The layers for all selected intervals will be automatically constructed by the system.

Additionally, a table has been constructed to classify the materials and their chronologies from CESGA's SDI database. In the material phase table, a series of columns are presented showing the chronological intervals of the material recovered inside the castle. The recording dates have been separated into 72-time intervals, which were then used to divide and present the results of the position marks of the elements in a new visualization model. General time levels, including those with empty records, have been shown in the first implementation of the system based on user requirements. This could create confusion and complexity in the visualization of the results, as shown in Figure 4.11. Therefore, this way of visualization becomes adequate when the number of intervals required to be represented is small, as in Figure 4.12. In addition, the client can review the level description by choosing the required

level as illustrated in Figure 4.13, where the dialog "this represents the unit UE2178=> 1467-1480 of time" represents a description for the selected level; also this figure contains the results using the improved Time Level Display paradigm, which eliminates the levels that have empty "element" records. Eventually, this paradigm was able to amend the resolution of the data to fit a particular Display Details Level (LOD) and represent many objects in the same coordinates with their date of appearance.



Figure 4.11: Layer of time levels.



Figure 4.12: Small number of levels.



Figure 4.13: Improved time-level visualization.

4.4.4 Equalizing Number of Levels

Often multiple paradigms are needed to give the archeologist a better understanding of the data. Three additional techniques provided by ArVS include “Equalizing the Number of Levels”; “Equation of Level Contents”; and “Divide With Plot”. Each of these techniques may be used as a tool by archeologists to increase their capacity to understand the site.

Each of these techniques helps archeologists to gain information about the number of artifacts found in the same place, which contributes to building their archeological analysis in three important ways : First, understanding the nature of the archeological site. Second, improving their ability to find new plans for exploration and excavations. Third, helping to transfer knowledge in the sector of Cultural Heritage.

Using the “Equalizing the Number of Levels” paradigm, the user first selects the object type that he wants to recover or visualize, where the elements are divided based on the selected object type. After that, the user selects the number of layers he wants, where the elements will be segmented. Finally, the user will click on the ‘submit and display’ button to complete the selection. These steps are shown in Figure 4.14, which represents the main placemark interface.

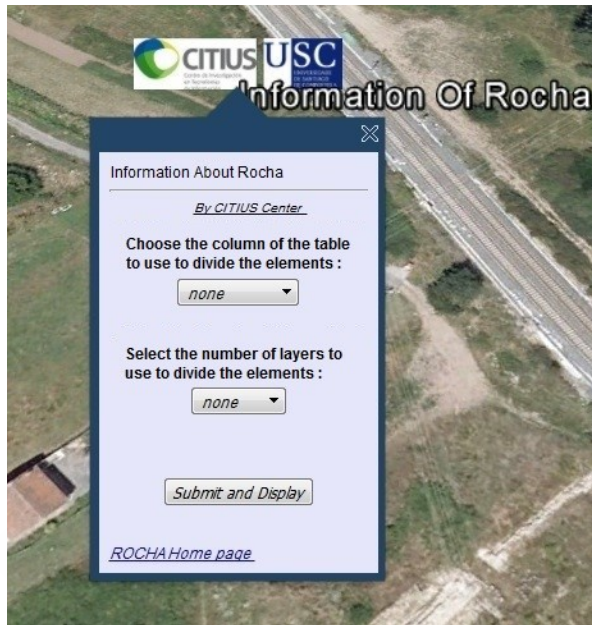


Figure 4.14: Main placemark interface.

Consequently, the elements would be segmented and displayed based on the number of layers selected by the user. In addition, a description of each layer would be displayed as well as other related information such as the number of elements in each layer, the name of the selected property (column in the proper table in the database) and the method of dividing the elements. The description of this information, which represents the output of this method, can be followed in Figure 4.15.

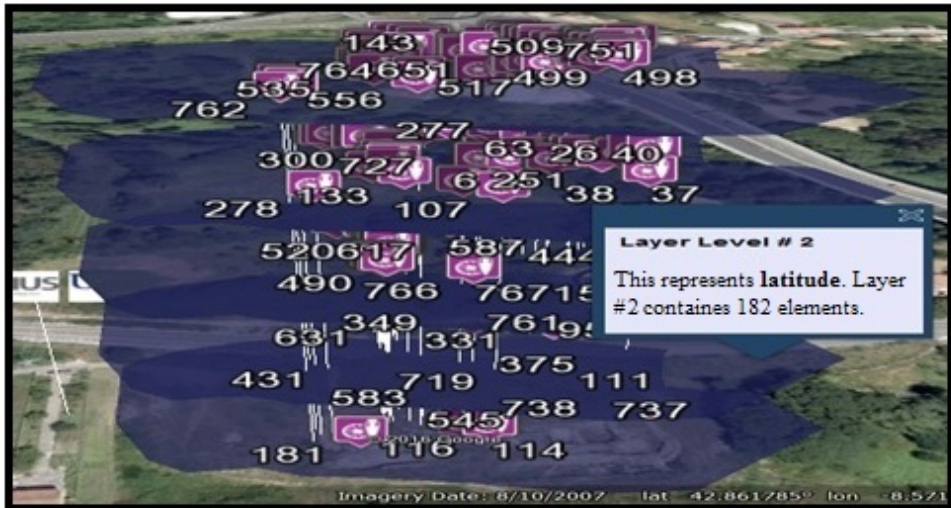


Figure 4.15: Results description of number of levels equalization.

If the number of elements to be represented in each layer is odd and the last layer contains a larger number of elements than other layers, then the last layer will be placed within the description: Such a layer contains a number of elements different from other layers. This case is shown in Figure 4.16, where two elements have been added to the last layer.

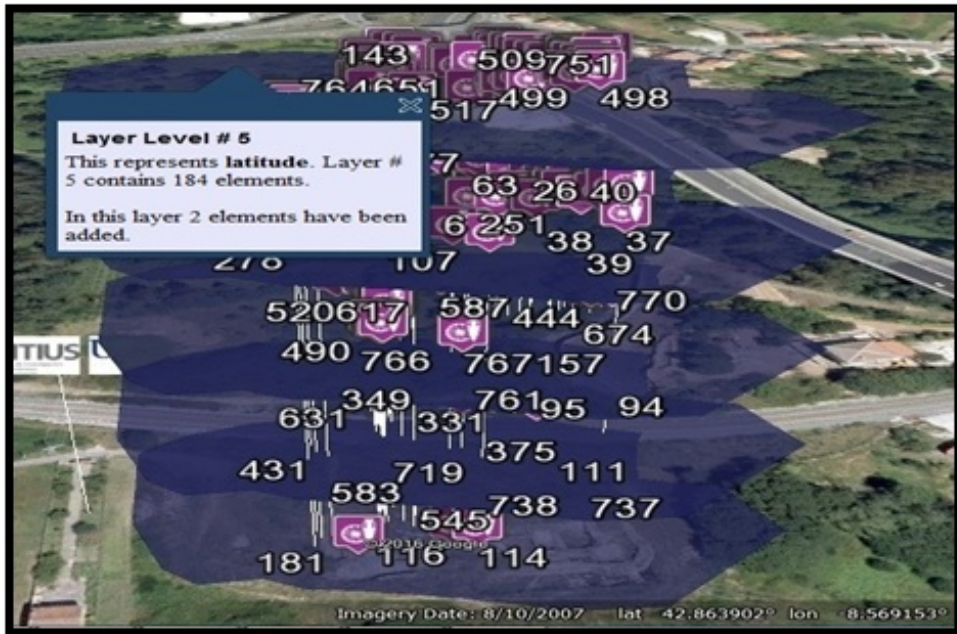


Figure 4.16: Elements addition step within equalization process of the number of levels.

4.4.5 Equation of Levels Contents

In general, splitting data into levels for visualizing is very difficult, especially if you want to choose the number of layers. The user must have information about the object in the database. If the datatype is numeric, she must know the values from highest to lowest, to be classified correctly. If the datatype is text, the complete string must be used to classify the objects correctly (objects are all grouped in layers, by the string that describes the property selected). This creates a need for a new automatic technique to help archeologists find a useful visualization based on distributing the artifacts to the various periods, whether their type is numeric or text.

Using the “Equation of Level Contents” paradigm, the number of layers and the entity will be selected by the user. However, the elements will not be distributed based on the counts of layers but depending on the contents of the entity selected. Therefore, intervals will be calculated (based on the equations explained in Chapter Three) and then the elements will be

divided based on these intervals. This means that the elements will be distributed over the layers and intervals that match their conditions. Figure 4.17 illustrates the description of layer level 1 based on this option.

In this case, the user has chosen a `date1` property, where the `date1` represents a date of the found the artifacts in the archeological site.

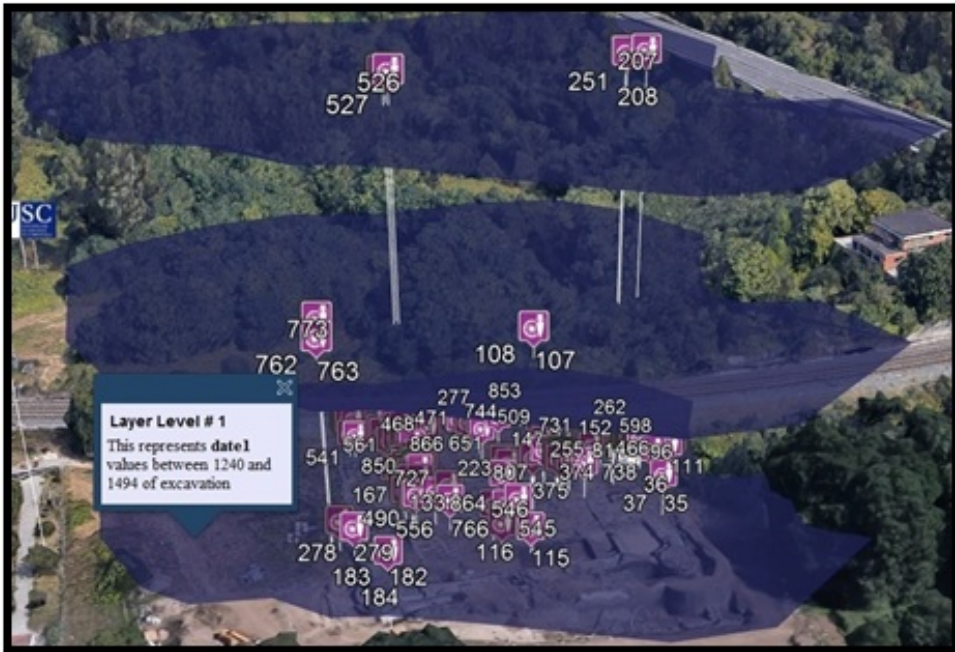


Figure 4.17: Description of layer level 1 based on equation of level contents .

Additionally, each layer contains a description of the name of the column selected and the present interval. The descriptions of layer 2 and layer 3 are shown in Figures (4.18 and 4.19) respectively.

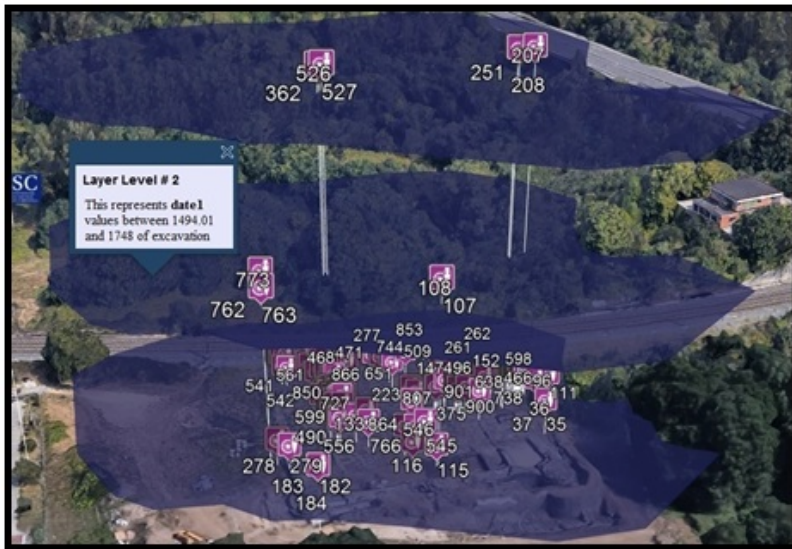


Figure 4.18: Description of layer 2 based on equation of level contents .

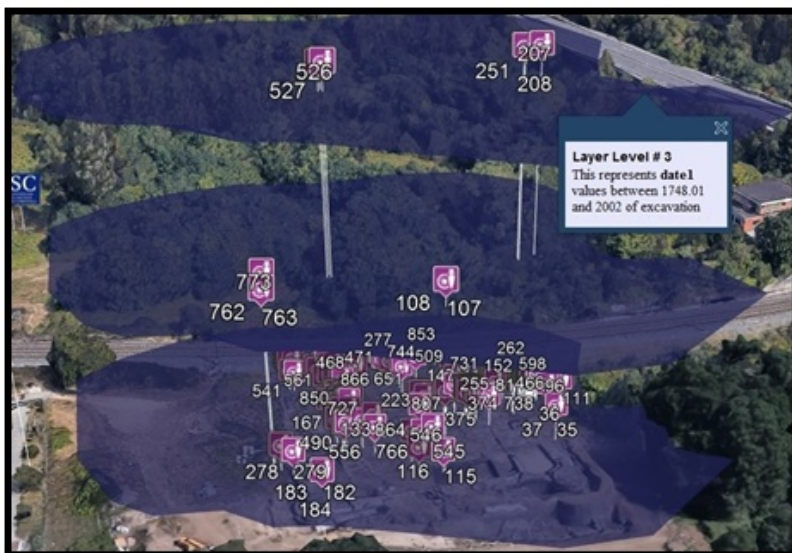


Figure 4.19: Description of layer 3 based on equation of level contents .

However, if the user selects a column involving data with text type, then this data will be displayed based on their particular column without redundant repetition, where each element of data will be divided on a layer. An example of this case is shown in Figures (4.20, 4.21, 4.22), where the “material” column has been selected. The column contains the type of data, text; thus, the program will hold the data without redundancy by dividing each one of them on a separate layer. In this example, the column involves six materials, then six layers will be constructed and each one of them will be adjusted based on the type of material.

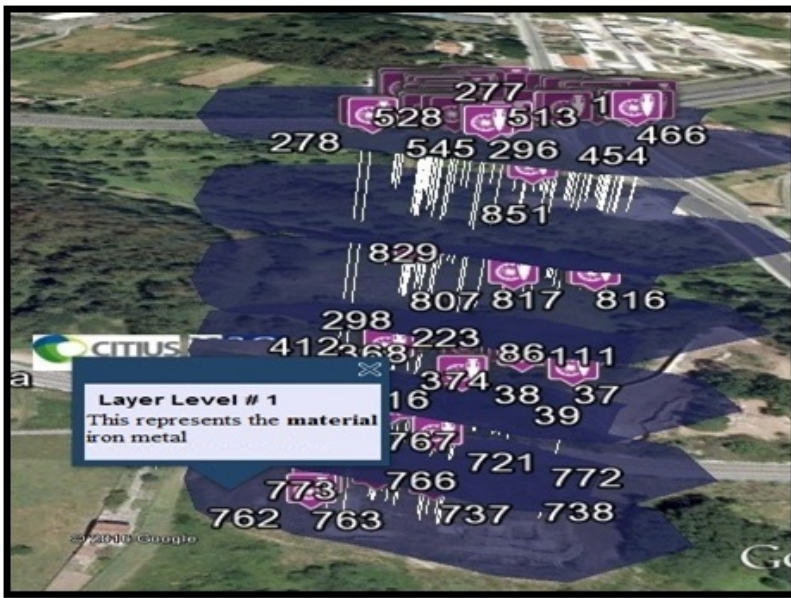


Figure 4.20: Description of Iron Metal layer.

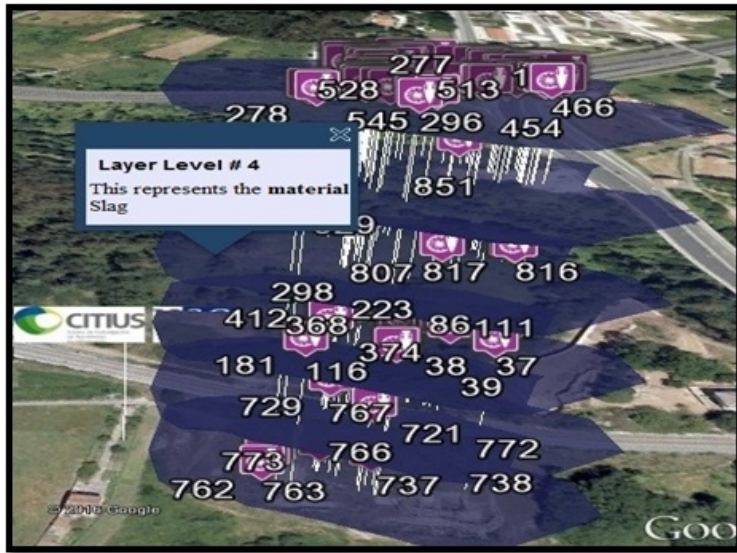


Figure 4.21: Description of Slag material layer .

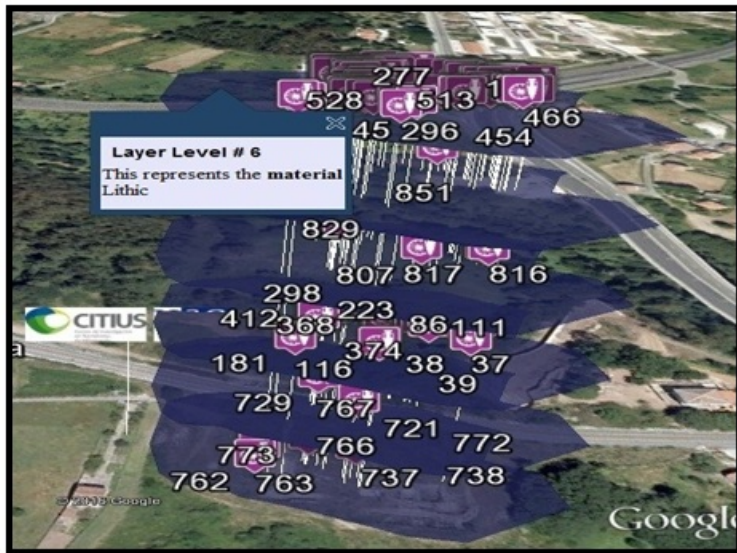


Figure 4.22: Description of Lithic material layer .

4.4.6 Divide with Plot

One of the essential requirements of visualization techniques is to contribute and present a smooth and precise analysis for archeologists and users. After applying the previous techniques, problems may remain regarding complex visualization, when the technique is applied to big data. For this reason, the author developed the “Divide With Plot” paradigm to overcome the problem of complexity and overlapping data.

The DWP technique provides a graph illustrating the summary of the processes of visualization and data distribution. The graph shows the critical data such as the number of archeological pieces in each period and the number of layers, which makes it easier to create an archeological plan.

Overall, the operation of this method is similar to the previous two methods. However, it is distinguished from these methods by the appearance of the plot on the results screen, where it illustrates the division of data over layers. Moreover, the data can be analyzed by this plot in a quicker and more accurate way. The general view of the plot interface is shown in Figure 4.23.



Figure 4.23: General view of plot interface .

An example of this method is given by the following Figures 4.24, 4.25, 4.26, where the metadata 'longitude' has been selected and the number of layers has been set to 3. Hence, the data related to the metadata selected, the number of layers and the interval description within each layer can be shown by pressing on the chosen layer. Then the data may be clearly, easily and accurately analyzed.

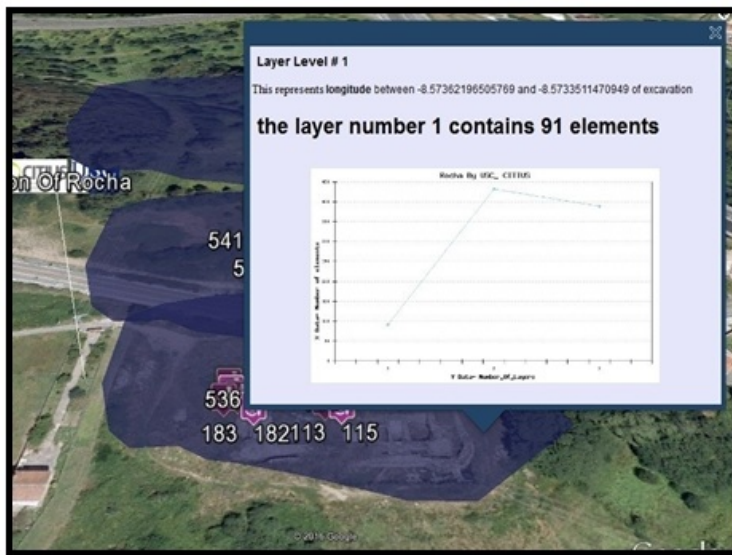


Figure 4.24: Description of layer 1 through graph drawing plot .

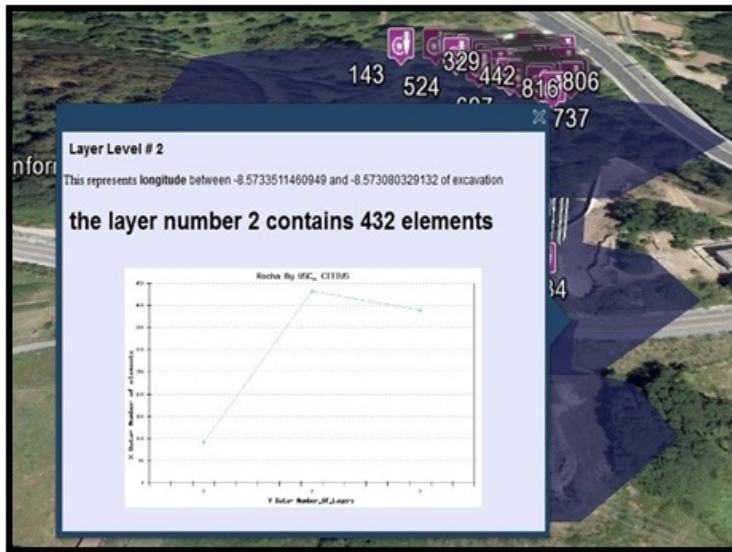


Figure 4.25: Description of layer 2 through graph drawing plot .

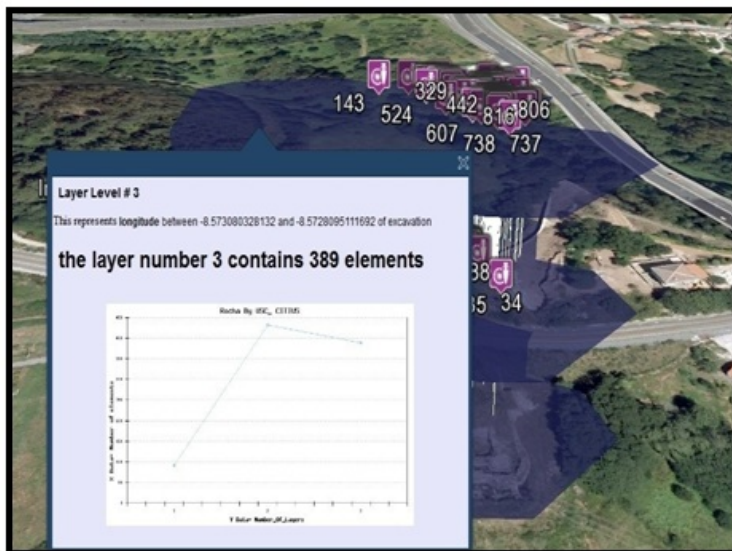


Figure 4.26: Description of layer 3 through graph drawing plot .

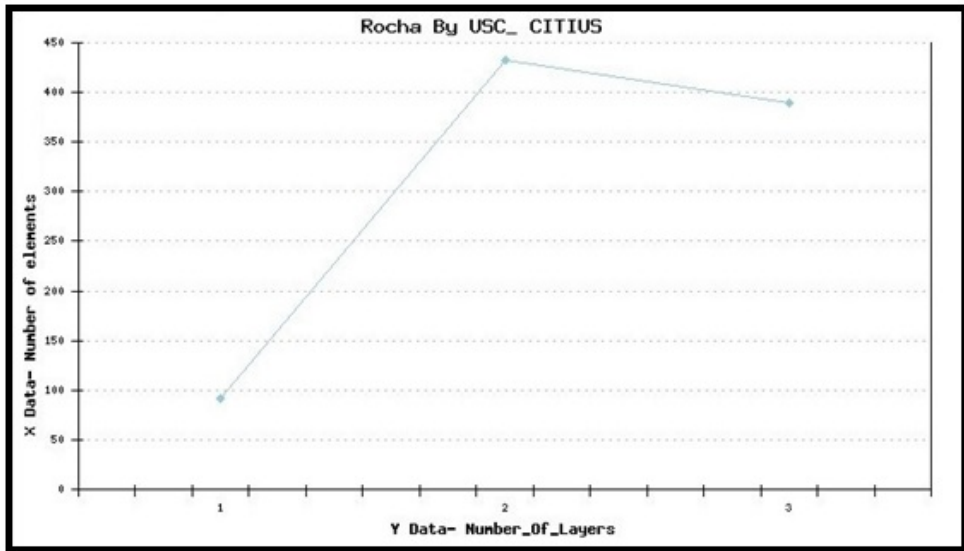


Figure 4.27: Relation between number of layers and number of elements.

In Figure 4.27, the user can see more details about the relation between number of elements in every layer depending on the column that chooses it. In this case the user selected the longitude column. We can see the relationship between the number of layers and the number of elements in each layer. This helps the archeologists when working with any critical column.

4.5 Environment of 3D Models

Archeological sites in Europe and Asia are unique pieces of art scattered in the cities as standing symbols of ancient civilizations. Due to their location, these archeological locations witness different environmental conditions which affect their status and sustainability besides terrorism and wars. This supports the need to have a 3D archeological system for publishing knowledge and preserve all spatial and artifacts information for each historical castle, which can be used later for monitoring purposes and virtual tourism.

Therefore, the author suggested making 3D models to visualize and analyze, and this gives the opportunity to preserve the heritage and archeological data at all countries suffering from

the destruction of structured archeology and information, due to terrorism and wars as we mentioned before.

This section shows how we can introduce 3D virtual models of real objects into the Google Earth representation system. In order to give an example, we continue focusing on the Rocha Castle archeological case. In this case the “real object” was destroyed in the past and we must recreate how the castle was, using various kinds of evidence, and the real dimensions that were found in the ground.

In general, the introduction of this kind of elements in our virtual geographic environments (VGE) can help the archeologists to analyze information more correctly, to present data in a kindlier way, and to make the Human Computer Interaction in our VGE more attractive for non-expert users. In some cases, where reconstructions were made using very reliable sources (or even using data from a real existing building) representation could help to preserve and protect heritage and archeological data. In addition, this gives a chance for any user to have virtual tourism with a low cost.

Google Earth supports managing three-dimensional geospatial data through the Keyhole Markup Language, known as KML. KML is a file format based on XML used to represent geographic data. KML has actually become an international standard.

We can create KML files to pinpoint locations, expose rich data in new ways, and add image overlays. Google Earth makes use of users’ submissions in KML format. This makes Google Earth simply based on 3D maps.

While powerful modeling tools like SketchUp are available, it still requires a lot of manual labor to model each building, like the Golden Gate Bridge or Sydney Opera House, that were hand modeled [26].

The lack of available images and Rocha castle documentation was the major challenge that faced the researcher within this thesis. Thus, the descriptions provided by CESGA’s archeologists as well as an image provided by other archeologists have been used within the system implementation [122]. The utilized image represents the real design of the castle, which is separated into three key phases based on this image. Within the first stage, the exterior walls with the primary gate were designed. The towers and interior walls were then designed as presented in Figures Figure 4.28-B and C. The details with high accuracy have been employed within the design stages, like keeping the straight slash line and actual forward line within the walls. Although these details complicated the design stages, the model obtained was added and implemented as a layer within the system in a successful way as shown in Figure 4.28-A.



Figure 4.28: Different Views of the Rocha Castle Model.



CHAPTER 5

HUMAN-COMPUTER INTERACTION TECHNIQUES OF (ARVS)

5.1 Introduction

In the past decade, human computer interaction with GIS has increasing attention among users, researchers, and developers.

The Human-Computer Interaction (HCI) concept considered as a discipline is concerned with the design, implementation and evaluation of interactive computing systems for human uses and the studies of significant phenomena surrounding them [123].

Between the 1970s and 1980s, GIS applications were managed by command languages accessible only by expert operators. In the second half of the 1980s, the first graphical user interfaces (GUIs) were developed [124]. Since then, interest in developing new and easy-to-use interfaces has been increasing, in order to remove the necessity of memorizing commands by visual feedback tools [124].

After all this time, however, GIS user interfaces are still complicated, hard to use and learn, and lacking in any theoretical or consistent conceptual framework [125].

Nowadays, the GIS domain is positively impacted by HCI tools that have received wide acceptance by organizations, institutions, and individuals. Recent trends in technology have been rapidly improving everyday life, and making tasks more efficient, by helping people to perform them in faster and more straightforward ways.

In addition, interaction devices such as the Microsoft Kinect sensor and different types of depth/IR cameras like PMDTec 3k-S and PMDTec CamCube 41k have helped the advancement of innovative and natural user interfaces (NUI), enabling mechanisms for HCI [126, 127].

In general, we can say these human-computer interaction mechanisms have depended until now on generic hand tracking algorithms, mainly dedicated to specific devices and not standardized [128].

In this thesis, we focused on the field of scientific geodata visualization applications through GIS (with a case study based on archaeological data). In this context, a universal interactive hand gesture must be derived and implemented.

As we mentioned before, Human-Computer Interaction focuses on how to design computer technology that is as easy and pleasant to use as possible. A vital aspect of the design discipline is the notion of “usability,” which is often defined in terms of efficiency, effectiveness and satisfaction [129].

There are many previous studies and applications available in the field of HCI with GIS such as [130, 131, 132, 133, 134].

However, the software in these studies suffers limitations such as lack of compatibility with new versions of the systems, and various other constraints. Thus, there is a need to build new interaction techniques to overcome these limitations.

The new techniques we propose are scalable and dynamic and can work with different GIS applications. They do not depend on special arrangements, as we will explain in the next sections.

We have used and implemented three multi natural interface mechanisms (voice, gestures, and mouse) as ways to interact with the system. Each mechanism has a specific function. The voice is used to control directions such as Left, Right, Up and Down in navigations, and also with speech recognition to convert to text that can be understood by the system. Gestures are used for application control for actions such as Zoom in, Zoom out, or Pan the map. The mouse is used to activate and control the pointer showing the current position on the map. We have considered the specific interactions between the system and the user, and we provide interaction in a usable way that is fun and attractive as well as precise.

Nowadays, the easy use of GIS contributes to the wide acceptance of GIS systems by organizations, institutions or personal users. Online 3-D virtual globes are considered an example in the context of modern GIS applications used to visualize and explore multiple domains

such as health data or archeological data [135, 136]. However, one or more traditional input devices (e.g. a 3-D mouse, traditional mouse or keyboard) are typically used to interact with virtual globes.

This chapter discusses the development and implementation of a Kinect -based 3D gesture recognition system for interactive manipulation of 3D objects in GIS applications, especially Google Earth (due to the reasons previously mentioned), to use in educational and archeology visualization software such as our Archeological Visualization System (ArVS).

We chose the Kinect device for researching because it integrates with visuals and depth data. Furthermore, it is remotely controlled and is used as a measurement system by providing data at a high accuracy frame rate [137, 138]. In addition, a Kinect is designed as a controller for multiple orders.

The system developed is based on multiple techniques and multidimensional geodata interaction and visualization, detecting and tracking human hands from the images captured by a Kinect sensor, and recognizing human gestures and voice.

5.2 Human Computer Interaction Techniques

This section discusses the techniques developed in this thesis, as a step on the way to solving the problem of using conventional GIS interfaces. Those interfaces cause limited productivity by not being intuitive enough to new users and by creating extra delays due to their classic methods for interaction.

As is already well known, GISs are playing increasingly significant roles in the real world, in areas that include making political decisions (urban planning, environmental development, etc.), influencing commercial developments (natural resources exploitation, geographical trade tendencies), as well as in our ordinary life (car GPS, tourism planning, etc.). The abilities of GIS applications have expanded, and their scope has been broadened by the generalization of software such as Google Earth, which has added another dimension to navigation [130].

The traditional communication methods for GIS applications limit usability and slow down the interaction that happens when using conventional devices such as a mouse and a keyboard. However, the human voice and motion system can naturally create actions through the use of speech or gestures in three dimensions.

Overall, the quality of the interactive interface has a high impact on the usability of geographic information systems. Traditional interactive interfaces have an usability problem . Hence, the need has emerged to develop and enhance traditional interactive elements through using new HCI devices (e.g., Leap Motion and Kinect sensors, which recognize hands-free gestures and register voice). For this reason, all changes in the way of dealing with virtual globes are always welcome in the context of the HCI field. As a step on the path of development in this work, a new set of HCI techniques are proposed (see Figure 5.1). These techniques are discussed in the following sections. All of them have been implemented and tested at Information Technology Research Center (CiTIUS) (Spain) and the Royal Jordanian Geographic Center (Jordan), which supported our assumptions about the importance of these techniques for easy and natural interaction.

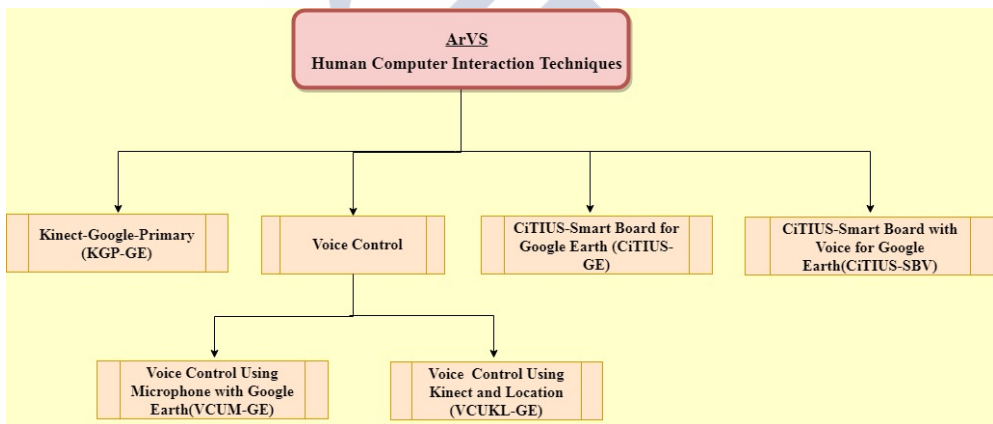


Figure 5.1: Human computer interaction techniques.

5.2.1 Kinect – Google – Primary with Google Earth (KGP-GE)

This technique includes methods for navigating to cities by pronouncing the name of the desired location, controlling all directions of the map through gestures, and using the mouse control to select any position (objects) on the map and activate it by mouse pointer control.

Furthermore, the KGP-GE method has been used to define different browsing mechanisms (gestures, voice, and mouse) that can be both unconventional and attractive. Any user with or without experience in the GIS field or the field of computer explanation, in a general sense, can deal with these approaches. This method is based on combining different principal methods


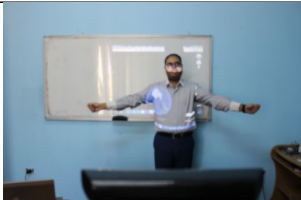

with each other using Microsoft Speech Library in order to facilitate searching for a certain location.

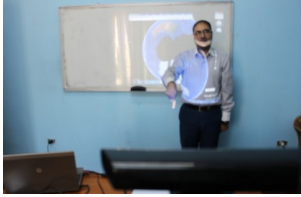
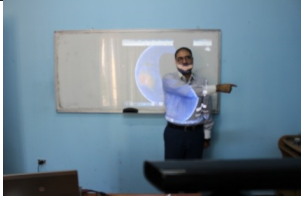

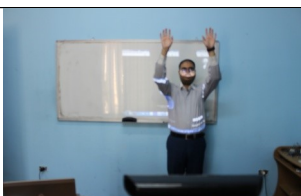

This library is responsible for speech recognition functions (speech-to-text). The speech recognition converts words spoken by the user into text, to specify the name of the city that was vocalized, and to accomplish tasks such as navigation to the desired city.

Hence, the method should combine gestures, which represent the navigation of hands at different orientations; mouse movements, used for selecting objects; and voice recognition, used to navigate to the desired city.

We conclude that the benefits of this technique include flexible input methods and support for short and straightforward words. This can enhance the accuracy of speech recognition and control processes and support high-performance control.

The approaches used in this method are summarized in Table 5.1.

KGP-GE (Kinect – Google – Primary for Google Earth Method)		
Example of Gesture	Function and Action of The Gesture	How to Perform the Gesture
	Zoom In	Stretch your arms forward
	Zoom Out	Open your hands outwards
	Up	Press your left hand to your side and push it down and raise your right hand above your head

	Down	Press your left hand to your side and push it down. Lower your right hand forward under your belt
	Left	Press your left hand to your side and push it down. Bend your right arm to the left direction on the left shoulder level
	Right	Press your left hand to your side and push it down. Pull your right arm straight to the right direction at shoulder level
	Switch to mouse mode and Switch back to keyboard emulation mode	Raise both hands above your head
	Switch to voice mode	Raise your left hand above your head




 <p>First, Second ,and Third steps</p>	Left Click	As Kinect recognizes the distance from your hand to the sensor, clicking is possible by moving your hand just a bit above upper belt level. Thus, if you just make a little motion, the sensor should recognize that and execute the click on the position where the mouse cursor was when you started the motion.
 <p>Vocalization of the word: <i>Keyboard</i></p>	Activate the navigation program to enable detection of hand gestures	Speak the word <i>Keyboard</i> .
 <p>Vocalization of the word: <i>Mouse</i></p>	Switch to mouse control using gestures	Speak the word <i>Mouse</i>

Table 5.1: Approaches used within KGP-GE method

As mentioned before, these techniques provide the flexibility of different input modes, so users can avoid the excessive use of one method alone during a long period of interaction with the computer. Users can have several options for their interaction methods, and make use of simpler and shorter speech words.

5.2.2 Voice Control

Voice Control Using Microphone with Google Earth (VCUM-GE)

Graphical interfaces for GISs typically require users to use difficult keyboard and mouse sequences to accomplish their tasks. This can be a significant barrier for new or occasional users and even for experts. Precise control of 3D maps can be especially challenging. To help address these challenges, we developed the VCUM-GE technique to support multiple voice recognition devices. This technique allows intuitive control as if users are directly manipulating 3D objects and navigation through sounds.

We can summarize the benefits of VCUM-GE as follows:

1. Support of simpler and shorter speech words (thus enhancing the accuracy of speech recognition).
2. Improved error avoidance to reduce errors.
3. Absorption of a more substantial number of environmental situations, tasks, and users.

Different types of voice recognition devices can be used by this method to control the system by voice, such as microphones, including individual or standard Kinect microphones.

This technique is done by assigning the keywords for browsing control according to the commands for various GIS applications such as the Google Earth program.

Based on above the users can then do browsing in an effective way and with minimal effort. Also, this method can help disabled people to accomplish tasks like browsing with absolute ease.

The main keywords that are used with this method are shown below (Table 5.2), where these words have been carefully selected to indicate their function in natural language.

Keywords (spoken)	Actions
Zoom in	Make the image of the map appears larger and nearer; execute once (10 meters down) and stop
Zoom out	Make the image of the map appears smaller and farther away; execute once (10 meters up) and stop
Stop	Finish any current operations and stop
Up	Move to a higher position (top of the monitor)
Down	Move to a lower position (bottom of the monitor)
Go to Right	Go in the right direction (right of monitor)
Go to Left	Go in the left direction (left of monitor)
Long zoom in	Make the image of the map appear much larger and nearer; execute for a long period
Long zoom out	Make the image of the map appear much smaller and farther away; execute for a long period
Navigation	Activate the navigation program and control processes by using the previous keywords (Stop, Up, Go to right, etc.)
Cities	Allow the user to speak the name of the desired city, and go directly to this location name

Table 5.2: Keywords of the VCUM-GE method

Voice Control Using Kinect and Location (VCUKL-GE)

In the VCUM-GE technique, the user is not able to choose any 3D object from the GIS interface. For this reason, we have developed an additional method called VCUKL-GE, extending VCUM-GE by combining several mechanisms, including voice for navigating and selecting cities, and movements to control the pointer.

This technique depends on using voice combined with the mouse which is used based on hand gestures. The cities property has also been added to this method to allow the user to choose the name of the desired city by vocalization.

VCUKL-GE will be initiated when the user speaks the words “mouse” or “navigation”. The mouse keyword is used to activate mouse control of the pointer on the map, while the navigation keyword is used to activate navigation mode and enable the control of processes using spoken keywords.

In addition, when in mouse mode, the user can activate other approaches easily by raising the left hand over the head. The keywords for this method are given in Table 5.3 .

Keywords (spoken)	Actions
Mouse	Enable control of the mouse using gestures
Cities	Allow the user to speak the name of the desired city, and go directly to this location name
Zoom in	Make the image of the map appear larger and nearer; execute once and stop.
Zoom out	Make the image of the map appear much smaller and further away; execute once and stop and stop after this
Stop	Finish any current operations and stop
Up	Move to a higher position (top of the monitor)
Down	Move to a lower position (bottom of the monitor)
Go to Right	Go in the right direction (right of monitor)
Go to Left	Go in the left direction (left of monitor)
Navigation	Activate the navigation program and control processes by using the previous keywords (Stop, Up, Go to right, etc.)

Table 5.3: Key words of the (VCUKL-GE) method

5.2.3 CiTIUS-Smart Board for Google Earth (CiTIUS-GE)

CITIUS-GE is based on interaction between the user and the projector screen wall. Users can control and interact with different applications by touching the projector screen wall with their hands. The most important features of this technique are dynamism and flexibility, in terms of positions and angles of devices.

The reason for creating this technique is the appearance of a requirement for a found additional technique that may be applicable not only to geographic information systems but for other domains as well such as archaeological, educational, health programs, and so forth.

To meet this requirement, we developed this interaction technique for overcoming past obstacles (such as speed execution of commands, non-adaptation with changes in the structural and position conditions of the devices).

Based on, we can be applied this method to GIS and many other domains. In this technique, CITIUS-GE, we also took into account recent technological developments of the motion sensing input devices. This method can be applied in developing countries, especially in the educational field, because the cost is low. Further, it is scalable, and it can adapt to continuous variations in environmental conditions.

During the design of the CITIUS-GE method, many challenges were faced, including:

- The variation in the screen size of the projection (Screen size is dependent on the distance from the projector to the wall).
- Different screen resolution from one device to another.
- Kinect angle on the tripod.
- The height of Kinect above the ground.

A basic prototype of this method was designed to overcome these challenges. In this method, three points (called set buttons) in the screen must be determined to calibrate the system and to improve the method's performance. This calibration process is needed because the origin of coordinates for the computer screen is different from that of the Kinect image. Kinect uses the center of the image as its origin, while the computer uses the upper left corner. Because the upper left corner (as well as the size of the image projected) depends on the distance between the projector and the wall, we need a calibration process.

Calibration is performed by the user by touching three points over the screen projection, representing the X, Y and Z dimensions. After that, the average dimension Z will be manipulated to identify the distance between the wall and the Kinect .

The origin of coordinates for the Kinect is located in the middle of the image, and it is represented by (0, 0). The origin of coordinates for the computer screen is located at the top-left corner of the image. The origin for the Kinect will be calculated from the place the user presses on the wall, and will then be transferred to the computer screen to increase accuracy. The angle and the displacement are evaluated based on these origins.

The spatial and detailed arrangement of the devices used to calculate the reference-point values is shown in Figure 5.2. The structure of devices can be changed, but the terminal types of equipment should be a projector and any HCI device (based on a 3D gesture-recognition system).

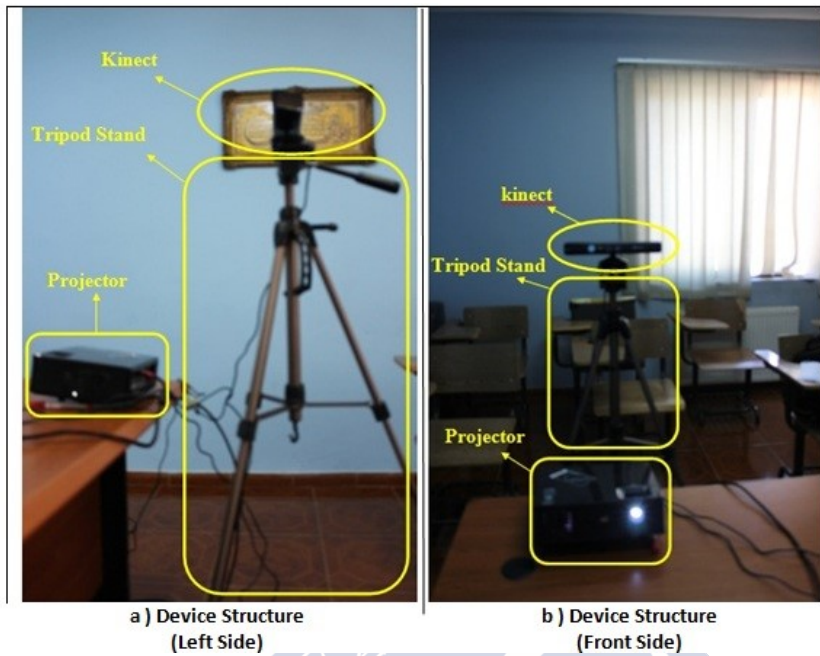


Figure 5.2: Spatial and detailed arrangement of the devices.

When using this technique, the calibration form (Set-Form) will appear for calculating the origin of coordinates and correct dimensions. This process will be done after the user touches and activates the three corners, as shown in Figure 5.3.

After that, Google Earth will automatically open and display the hide-top menu, which only appears when a hand is raised at the top of the screen.

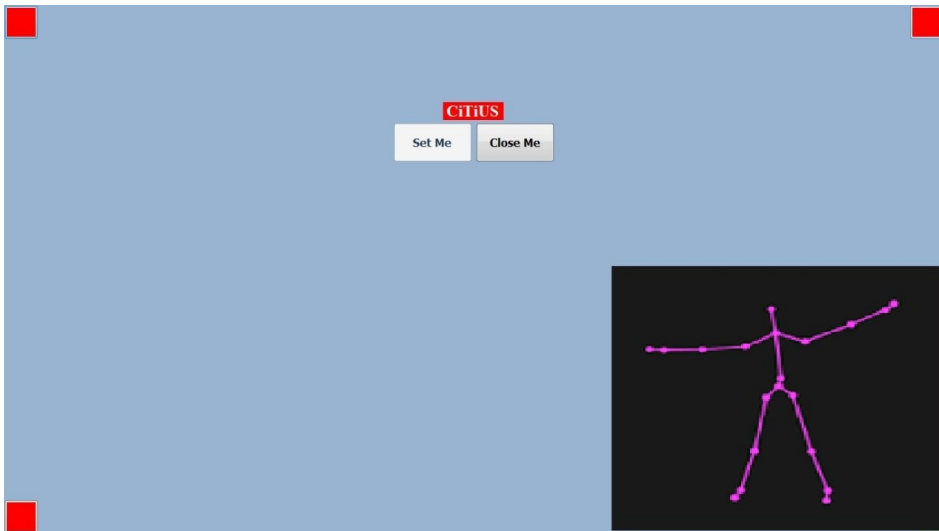


Figure 5.3: Main form of calibration (Set-Form).

The hide-top menu involves many buttons (shown in Figures 5.4 and 5.5). If one of these buttons is pressed, the activated status will emit a corresponding “operational” sound, and the status menu is presented in the lower part of the screen, where it indicates the status of the activation.

When the hand of the user clicks on the hide-top menu, the chosen button is activated if the distance between hand and Kinect reached to the value of “Z” (Z : Distance between Kinect and wall.) that was calculated by the calibration form. We have shown the steps of activating the calibration form in Table 5.4.

As shown in Figure 5.3 and Figure 5.4, when running the program, the main form of calibration (Set-Form) will display directly. Hence, the user can set the points of the corners when putting his hand on them. To aid in visualization, a skeleton is shown in the window at the lower right corner through the Right-Down Stream Form. The user must be aware of the movement of the skeleton’s hand. When the skeleton’s hand is fixed, the user will activate the click command.

After finishing this step, the system will show the desktop and activate the control menu (hide-top menu) at the top of the screen. This menu allows users to deal with various applications. The menu contains buttons, each associated with a particular action. Figure 5.5 explains the hide-top menu button functions.

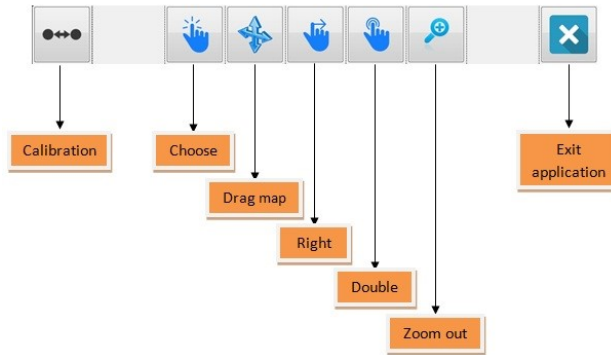


Figure 5.4: Hide top menu description (Button's name). .



Figure 5.5: Hide top menu buttons function .






CITIUS-GE CiTIUS_Smart Board for Google Earth method		
Example of Gesture	Function and Action of the Gesture	How to Perform the Gesture
	Set upper left corner button	Put your hand on the button (upper left corner on the screen); then click ¹ on this button to start the calibration process process
	Set upper right corner button	Put your hand on the button (upper right corner on the screen); then click on this button to start the calibration process
	Set lower left corner button	Put your hand on the button (lower left corner on the screen); then click on this button to start the calibration process process
	Show hide-top menu	Raise your hand to the top of the screen and directly show the hide-top menu
	Click any button on hide-top menu	Put your hand on any button on the hide-top menu to select it, it will be automatically clicked

Table 5.4: Calibration process using different buttons in the CITIUS_GE method

Table 5.4, shows how to set buttons to calibrate the dimensions using gestures, and how to activate and deal with the hide-top menu. The CITIUS-GE technique is flexible and adaptive, because when changing the variables (the position of the projector, the distance between Kinect and wall, and the structure of the devices, or the angle of the device), the user can continue to work smoothly and flexibly.

5.2.4 CiTIUS-Smart Board with Voice for Google Earth (CiTIUS- SBV)

We have further enhanced the CITIUS-GE technique, to obtain a more natural interaction between the user and the computer using voice commands. With this new technique, CITIUS-SBV, a user can save time, because the voice can be used to select a place for searching or to select a function as if a button had been pressed from the menu. This can achieve more precision and speed in carrying out orders compared with the CITIUS-GE technique.

The voice in this method is activated within the control procedures. The user can deal with the calibration form by putting one hand at the desired corner on the form, or the name of the corner can be mentioned by speaking orders (First, Second, Third) to set and store the values and to attain more accurate measurement. Table 5.5 shows the activation of corner points by name. This shows how to set buttons to calibrate the dimensions using the voice to specify each corner point by one of the words “First”, “Second”, or “Third”. This makes it easier for the user to perform the necessary calibration.

¹Click command can be performed in this technique, by using the timer (wait 5 seconds without movement), or clicking return key, directly on the keyboard, perhaps with somebody helping the user.




CiTIUS - SBV CiTIUS Smart Board with voice for Google Earth method		
Example of Gesture	Function and Action of the Gesture	How to Perform the Gesture
	Set upper left corner button	Put your hand on the button (upper left corner of the screen), then say the word "First" to start the calibration process
	Set upper right corner button	Put your hand on the button (upper right corner of the screen), then say the word "Second" to start the calibration process
	Set lower left corner button	Put your hand on the button (lower left corner of the screen), then say the word "Third" to start the calibration process process

Table 5.5: Calibration process using different buttons in the CITIUS_SBV method

After calibration, Google Earth may be controlled through spoken keywords instead of using the hide-top menu. Figure 5.6 illustrates the keywords for this method and describes the functions for each one.

This technique depends on the voice. Using the main calibration form, the user can set the coordinates of the corner points by speaking the name of each point. After that, if all points are assigned correctly, the system will calculate and convert the coordinate values to pixels and calculate the distance between the wall and the Kinect. Finally, the hidden voice form will be activated in this method to enable control of Google Earth by keywords.

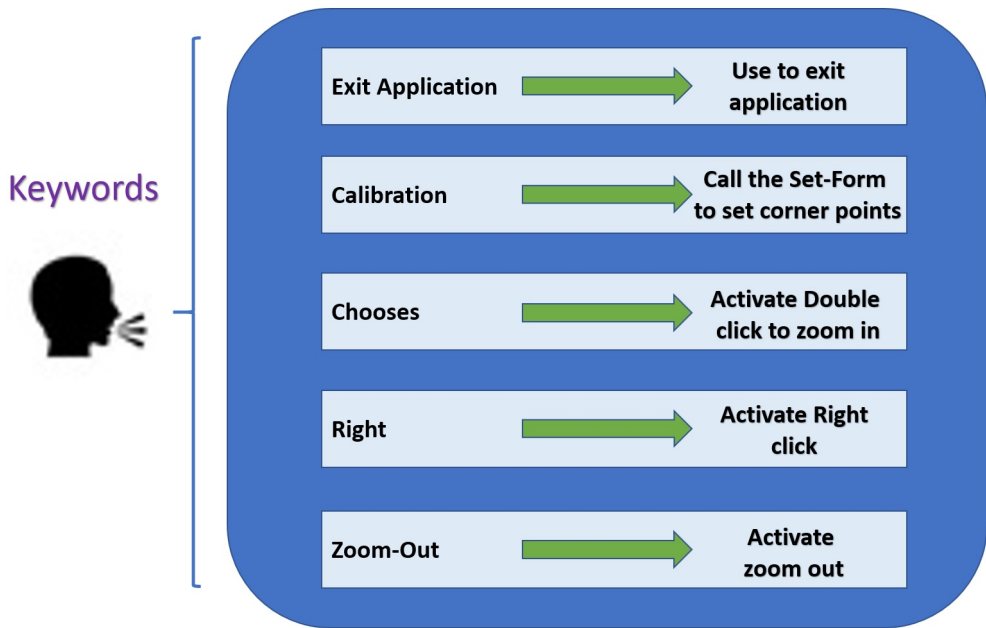


Figure 5.6: key words and functions of CiTIUS-SBV method .

5.3 Conclusion

Human-Computer Interaction for geographical information systems has become an important part of working life for users. In this chapter, we focused on how to interact with various GIS application by using new techniques.

In summary, we developed (as part of the ArVS system) multimodal-interaction techniques tested for Google Earth, but that can be used with various GIS and other applications. These techniques avoid the use of the standard devices, such as a mouse and keyboard. They involve gesture recognition with Kinect, speech recognition to give orders to the system (commands) and touching interaction with the wall projection.

These new multimodal-interaction techniques, involving voice, gestures, and mouse, form the basis for new, improved interactive interfaces.

CHAPTER 6

USABILITY EVALUATION OF THE ARVS

6.1 Summary of Chapter

In this chapter we will discuss the results of the usability evaluation of the Archeological Visualization System (ArVS); this process took place at the Royal Jordanian Geographic Center, during my research stage in 2017, and at Research Center in Information Technologies at Santiago de Compostela University. We have used two types of users: experienced and inexperienced in the use of GIS. The evaluation process is focused on visualization paradigms and human-computer interaction techniques.

We developed and used a questionnaire as an evaluation tool. The questionnaires were completed by the test subjects after working with the system for one day. This strategy was followed for both parts of the ArVS system: Visualization and HCI.

6.2 Introduction

Generally, the public visualization and human-computer interaction applications related to Geographic Information Systems such as SdVS are naturally enabling GIS users to access all geoinformation related to their life, and enabling them to use the technology purposefully to take into account their local knowledge and advance their aims [139, 140].

We can say that the usability of GIS products has improved immensely in recent years, but they still require users to have or acquire essential technical knowledge to achieve them [141]. This may present significant obstacles to non-expert users.

In such situations, the visualization and HCI issues, which are concerned with the usability or the validation of the interaction between humans and computer [142], and how computers influence people, corporations and community, must be addressed to achieve successful GIS applications. Thus, the usability evaluation can help to improve the design of GIS applications.

Usability can be measured by collecting user's opinions using questionnaires [143, 144, 145, 146, 147, 148]. In general, using a questionnaire is an easy and time efficient data-collection method. Many types of standardized questionnaires are available for measuring usability, such as:

- The System Usability Scale (SUS) [149].
- NASA Task Load Index (NASA TLX) [150].
- Software Usability Measurement Inventory (SUMI) [151].
- The After-Scenario Questionnaire (ASQ) [152].
- Post-Study System Usability Questionnaire (PSSUQ) [152].
- Computer System Usability Questionnaire (CSUQ) [152].
- Questionnaire for User Interface Satisfaction (QUIS) [153].

HCI also plays an essential role in the development of websites and computer systems, as it helps to develop “interaction techniques and to propose where and in what status these techniques and technologies might be put to best use” [154]. Surveys and questionnaires have been used within the Human-Computer Interaction (HCI) context and other domains since the early days of science as a primary source of data collection [155].

The questionnaire was developed to provide an easy test to allow with a minimum number of issues in the usability domain, comparisons between each one of the HCI techniques.

The features of the human-computer-interaction techniques in ArVS were explained in chapter 5. They include an interactive map tool that allows viewing and controlling of a map's features and functions in response to a user action.

Usability and HCI are becoming essential features of the Archaeological visualization systems (ArVS) development process. These features are important to enhance system abilities and achieve the requirements of users, both expert and non-expert.

In summary, geo-data is required by users to support their decision making. The applications that provide this geodata may be complicated, so evaluation of their usability is critical. There are various definitions of usability, but the most common description is given by ISO 9241 [156] “the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use.” For this reason, we will test our visualization and HCI system from the usability point of view.

6.3 Usability Evaluation Process of the ArVS

In this section, we will discuss the two parts of the usability questionnaires, the visualization and HCI in the ArVS, with the two types of users: Expert and Non-expert. The evaluation focuses on the software usability from the point of view of the design and implementation we have done.

The assessment of the functionalities and design of the visualization part in the (ArVS) was carried out through the development of a usability survey (Table 6.1). Notice in this survey that some questions contain two parts, A and B. Where this occurs, A is for the visualization part and B is for the HCI part.

The design of the questions was based on software usability questionnaires [157], especially on the System Usability Scale (SUS) questionnaire, which was developed by John Brooke in 1996 as part of the introduction of usability engineering to digital equipment systems [149]. Even though the methodology might seem old, its base is actually and widely used, as we can check in [158, 159].

The survey consisted of 13 items. These items include the assessment of diverse aspects: tasks, structure design, terminology and speed. Each of these items has four possible answers, which are ranged from 1 to 4, according to the degree of approval: 1 Strongly disagree, 2 Disagree, 3 Agree, 4 Strongly agree. The maximum overall score for the survey is 52.

In Figure 6.1, we have defined questions related to the usability and the requirements of the system (as expressed in our objectives in chapter one).

Items
Q1. I think it is an easy system to use.
Q2. I found the system has a good structure and organization.
Q3. The tasks I performed were very meaningful to me.
Q4. The tasks were usually interesting enough to keep me from getting bored.
Q5. A) I found the Paradigms structure design good enough for me, to perform the tasks. B) I found the current Technique structure design is good enough for me to perform the tasks.
Q6. A) The presentation of the user interface is pleasant and friendly. B) I think that I would like to use this technique frequently.
Q7. A) I am generally satisfied with the kind of work I performed in the different (HCI) Techniques and Visualization Paradigms tasks. B) I am in generally satisfied with the kind of work I performed in the Technique tasks.
Q8. I felt very satisfied with the amount of challenge in these tasks.
Q9. I know what stage of the system I am.
Q10. I felt very satisfied with the accomplishment I got in performing the tasks.
Q11. I felt very satisfied with the amount of independent thought and action I could exercise in the tasks.
Q12. I did not need any help to manage the program.
Q13. The processing speed of the System is fast.

Table 6.1: The Questionnaire for Usability Evaluation.

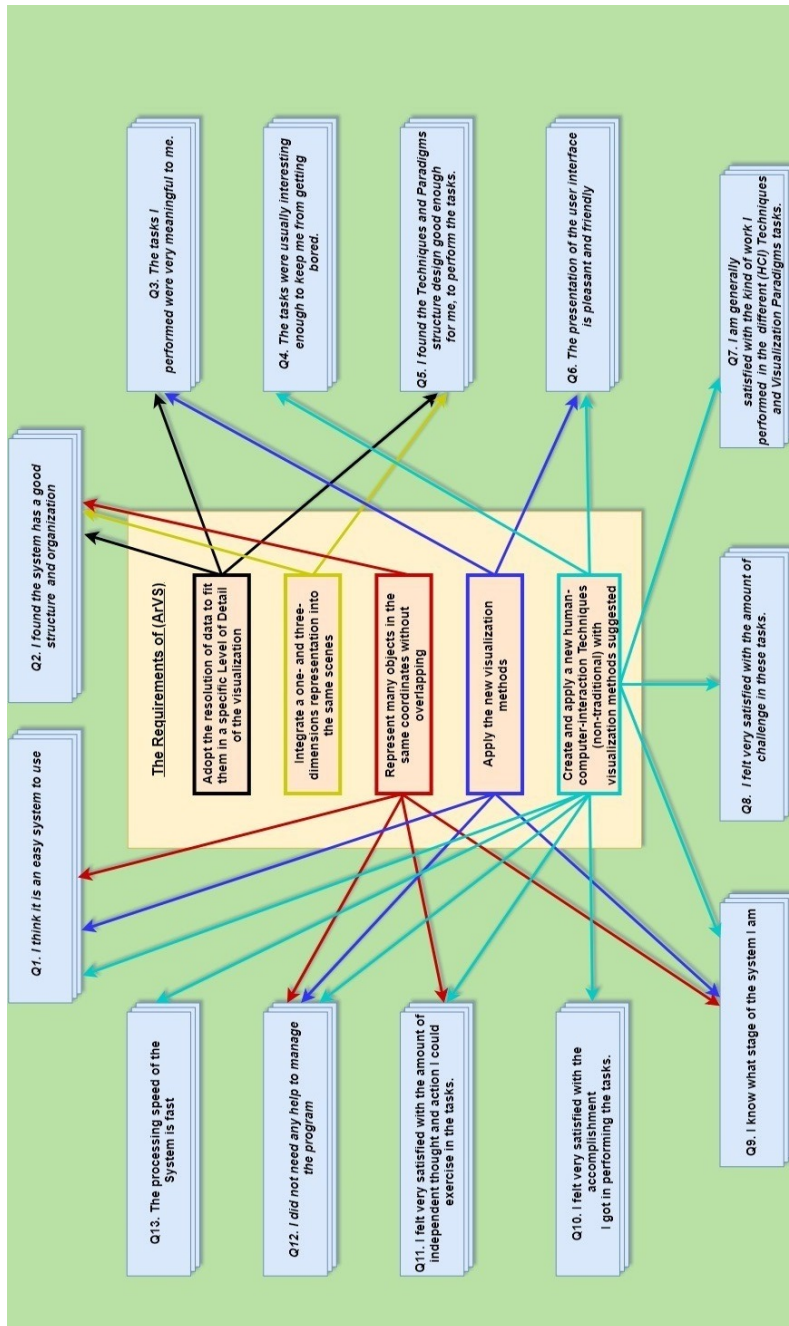


Figure 6.1: The relation between questions and the requirements of ArVS system.

As shown in Figure 6.1, the Q1,2,3 are related with How to adopt the resolution of data to fit them in specific Level of Details. In the same context, the Q2,5 are can summary the opinion about of how the system represented and integrated 1-3 dimensions into same scenes.

On another hand, we can know of the opinion the users about the ways to represent many objects in the same coordinates without overlapping by Q1,2,9,11, and 12.

Besides, we can know the point of view of users about the applying new visualization methods in the Q1, 3, 6, 9, and 12. Also, form the answers of Q1,4,6,7,8,9,10,11,12, and 13 we can be sure about the impression of creating and applying new human-computer interaction techniques.

In summary, we can see that all questions answer at least one objective. In this sense, all questions have sense and are meaningful. Furthermore, all requirements are covered by at least one question. Hence, as a result of the questionnaire, all requirements of the ArVS system have been validated and achieved.

6.4 Usability Evaluation for Visualization Part

The visualization part of the ArVS system evaluation was carried out as a proof-of-concept study with two experts and five inexpert users (see Table 6.2). All users received detailed explanations about the goal and the functionality of the visualization part in the (ArVS). The scores obtained from both expert and inexpert users were greater than 89% of the total score. This is considered to have been a successful outcome of the assessment. The results are shown in Table 6.2 and illustrated with a bar chart in Figure 6.2.

Items	Achieved Average Rating		
	Expert	Inexpert	Total
Q1	3.5	3.6	3.6
Q2	4.0	3.2	3.6
Q3	4.0	3.0	3.5
Q4	3.0	3.0	3.0
Q5 A)	3.5	3.8	3.7
Q6 A)	4.0	3.8	3.9
Q7 A)	4.0	3.8	3.9
Q8	4.0	3.8	3.9
Q9	4.0	3.8	3.9
Q10	3.5	3.6	3.6
Q11	4.0	3.8	3.9
Q12	2.5	2.8	2.7
Q13	3.5	3.0	3.3
TOTAL	47.5	45.0	46.3

Table 6.2: Results of Usability Evaluation using Questionnaire (Visualizations Part).

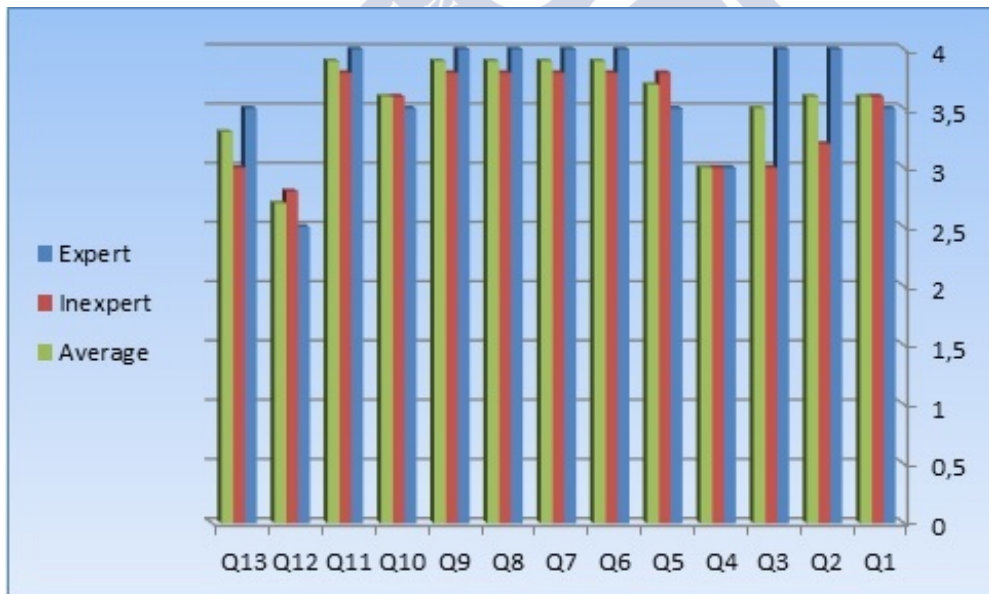


Figure 6.2: Chart of survey answers .

6.5 Usability Evaluation for Human Computer Interaction Part

In this section, we discuss the evaluation of the Human-Computer Interaction techniques in the (ArVS). This task also took place in the same research centers mentioned above: CITIUS and RJCG.

This evaluation process assists in determining which techniques achieved were the best from usability point of view, that were both, pleasant and easy to use for the target audience.

The surveys which we have applied in the next sections aim to give a comprehensive overview of some elements such as performing the tasks; meaningfulness; structure design and strengths, weaknesses, and challenges of such environments from the point of view of users.

The questionnaire was distributed after giving the users a day for applying each technique. The evaluation took place the next day. Based on that, the process consumed a period of ten days. The samples of users who participated in the surveys included two groups, one expert and the other inexperienced; each group contains five users.

Five questionnaires, to evaluate the usability of each of the HCI techniques, were completed by each of the 10 participants. In these questionnaires, we asked questions to focus on three aspects: satisfaction, effectiveness, and efficiency. The satisfaction questions highlighted the user's subjective reaction to using the system; the effectiveness questions focused on the ability of users to complete tasks using the system, and the quality of the output of those tasks; and the efficiency questions explored the level of resources consumed in performing the tasks.

In general, our evaluations and studies indicated that different users had different responses to the design of these techniques. In the following subsections, we will present the results for each technique separately, after which the results will be discussed objectively.

6.5.1 Assessment of Kinect – Google – Primary (KGP-GE)

As we described in chapter 5, KGP-GE is a technique that combines all the functions and facilities provided by the Kinect device in a new way in the context of GIS, based on gestures. We saw through the results analysis of this survey, that the degree of acceptance of the users is high, due to the ease of use and the high accuracy achieved when performing the functions. The results are given in Table 6.3.

Items	Achieved Average Rating		
	Expert	Inexpert	Total
Q1	4.0	3.4	3.7
Q2	4.0	3.0	3.5
Q3	4.0	3.2	3.6
Q4	4.0	3.6	3.8
Q5 B)	4.0	3.0	3.5
Q6 B)	4.0	3.6	3.8
Q7 B)	3.8	3.0	3.4
Q8	3.8	3.4	3.6
Q9	4.0	2.6	3.3
Q10	4.0	3.0	3.5
Q11	4.0	2.8	3.4
Q12	2.8	2.2	2.5
Q13	3.8	3.4	3.6
TOTAL	50.2	40.2	45.2

Percentage of 86.9

Table 6.3: Usability survey KGP-GE

This table shows that there is a significant consensus on this technique regarding using this method frequently. Also, the tasks were usually meaningful and exciting enough. But, when some users had concerns about this technique, the system provided help to manage the program.

On the other hand, users were satisfied with the kind of work performed with this technique and the amount of independent thought when using the different mechanisms. Where these mechanisms are working independently without overlapping each other, which contributes to the accuracy and concentration of user work.

Generally, through the overall survey results, this technique achieved the satisfaction of users by 86.9 percent.

In Table 6.4 we can see the Result of the survey about (KGP-GE) Using a Likert scale for each question. Also, the survey answers for (KGP-GE) are illustrated by the chart in Figure 6.3.

Questions	Total	Strongly agree	Agree	Disagree	Strongly disagree	Total
Q1	10	70%	30%	0%	0%	100%
Q2	10	50%	50%	0%	0%	100%
Q3	10	60%	40%	0%	0%	100%
Q4	10	80%	20%	0%	0%	100%
Q5 B)	10	50%	50%	0%	0%	100%
Q6 B)	10	80%	20%	0%	0%	100%
Q7 B)	10	40%	60%	0%	0%	100%
Q8	10	40%	40%	20%	0%	100%
Q9	10	40%	40%	20%	0%	100%
Q10	10	50%	50%	0%	0%	100%
Q11	10	50%	40%	10%	0%	100%
Q12	10	10%	50%	30%	10%	100%
Q13	10	60%	40%	0%	0%	100%

Table 6.4: Likert Scale Results for KGP-GE technique

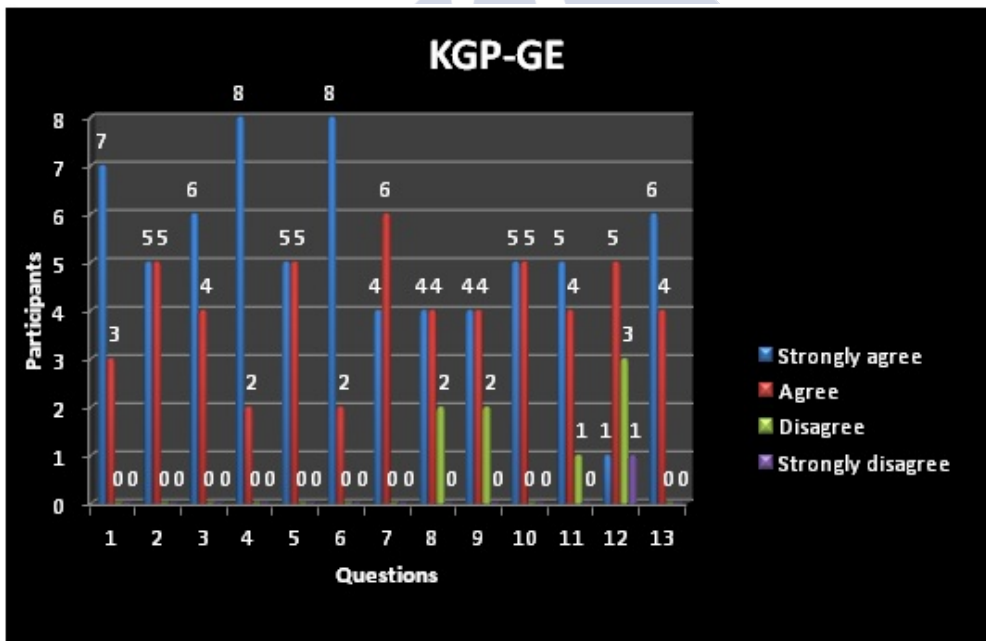


Figure 6.3: Chart of survey answers for KGP-GE .

6.5.2 Assessment of Voice Control Using Microphone with Google Earth (VCUM-GE)

The VCUM-GE method was evaluated in the same manner as described above for the KGP-GE method. We noticed that users were satisfied with the use of this technique. We believe the reason for that was because this technique was designed and based on the voice mechanism. As can be seen from the results in Table 6.5, all users strongly agree on the ease of use of this technique. At the same time, many users have a moderate agreement with the technique structure design. We believe that the main reason for that is the inability to choose any location on the map through using speech. This is a simple obstacle to this technique, and it was a major reason for the development and creation of the CVUKL_GE technique.

Again, Table 6.6 gives the results of this survey on the Likert scale, and Figure 6.4 presents these results in the form of a bar chart. We note that users were satisfied and agreed with the features of this technique such as the effort required to perform tasks, and the ability to distinguish what stage in the system they are at.

Items	Achieved Average Rating		
	Expert	Inexpert	Total
Q1	3.8	3.8	3.8
Q2	3.2	3.4	3.3
Q3	3.0	3.4	3.2
Q4	3.6	3.4	3.5
Q5 B)	3.0	3.4	3.2
Q6 B)	3.6	3.4	3.5
Q7 B)	3.0	3.2	3.1
Q8	2.4	3.4	2.9
Q9	3.0	3.2	3.1
Q10	3.0	3.4	3.2
Q11	2.8	3.6	3.2
Q12	3.2	3.2	3.2
Q13	3.4	3.8	3.6
TOTAL	50.2	50.2	50.2

Percentage of 96.5

Table 6.5: Results of Usability survey VCUM-GE

Questions	Total	Strongly agree	Agree	Disagree	Strongly disagree	Total
Q1	10	80%	20%	0%	0%	100%
Q2	10	30%	70%	0%	0%	100%
Q3	10	30%	70%	0%	0%	100%
Q4	10	50%	50%	0%	0%	100%
Q5 B)	10	20%	80%	0%	0%	100%
Q6 B)	10	50%	50%	0%	0%	100%
Q7 B)	10	10%	90%	0%	0%	100%
Q8	10	20%	50%	30%	0%	100%
Q9	10	10%	90%	0%	0%	100%
Q10	10	20%	80%	0%	0%	100%
Q11	10	30%	60%	10%	0%	100%
Q12	10	20%	60%	10%	10%	100%
Q13	10	60%	40%	0%	0%	100%

Table 6.6: Likert Scale Results for VCUM-GE technique

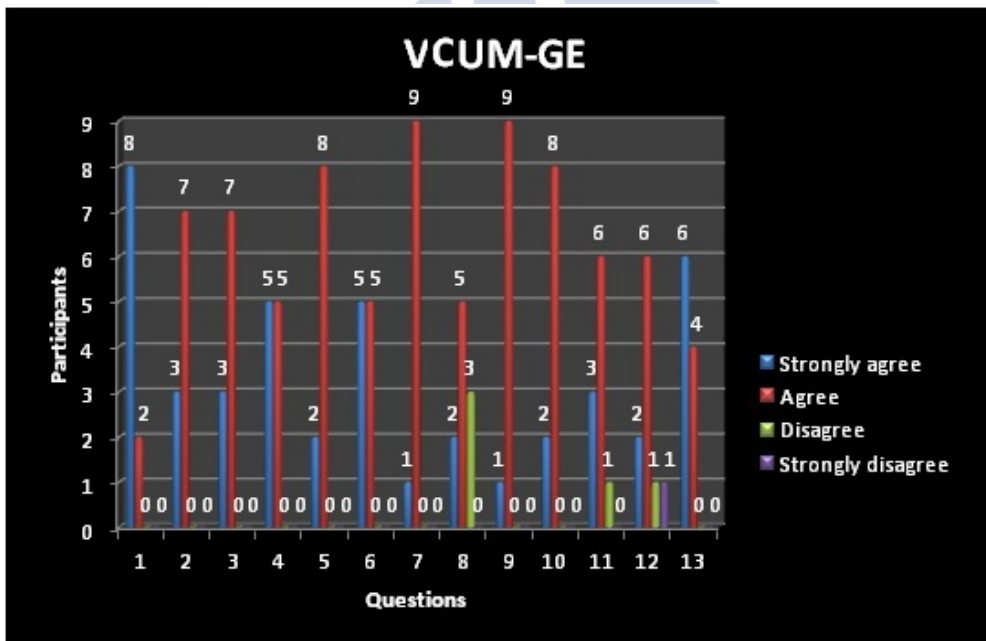


Figure 6.4: Chart of survey answers for VCUM-GE .

Based on the analysis of the above answers we can ensure that this technique has been satisfactory for users because they can complete tasks efficiently with an accurate output of those tasks.

6.5.3 Assessment of Voice Control Using Kinect and Location (VCUKL_GE)

As mentioned earlier the main reason for proposing this method is to overcome the obstacle in the previous technique, whereby the users cannot choose any 3D object and interact with interfaces on the map.

This technique solves this problem by allowing the possibility of using the mouse unit in combination with the rest of the earlier functions. The results have been highly agreeable, so this technique has attracted users' approval (see Table 6.7).

Items	Achieved Average Rating		
	Expert	Inexpert	Total
Q1	4.0	4.0	4.0
Q2	3.8	3.8	3.8
Q3	4.0	3.8	3.9
Q4	3.8	3.4	3.6
Q5 B)	3.6	3.2	3.4
Q6 B)	4.0	3.8	3.9
Q7 B)	3.6	3.4	3.5
Q8	3.6	3.6	3.6
Q9	4.0	3.4	3.7
Q10	4.0	3.2	3.6
Q11	3.8	3.6	3.7
Q12	3.6	3.0	3.3
Q13	3.8	3.8	3.8
TOTAL	49.6	46.0	47.8

Percentage of 91.9

Table 6.7: Results of Usability survey VCUKL_GE

As the table shows, all users strongly agree on the ease of use of this technique, which indicates the success of the technique from all aspects that have been considered. Also, we can see the specific results for each question in Table 6.8 and Figure 6.5.

Questions	Total	Strongly agree	Agree	Disagree	Strongly disagree	Total
Q1	10	100%	0%	0%	0%	100%
Q2	10	80%	20%	0%	0%	100%
Q3	10	90%	10%	0%	0%	100%
Q4	10	60%	40%	0%	0%	100%
Q5 B)	10	40%	60%	0%	0%	100%
Q6 B)	10	90%	10%	0%	0%	100%
Q7 B)	10	60%	40%	0%	0%	100%
Q8	10	60%	40%	0%	0%	100%
Q9	10	70%	30%	0%	0%	100%
Q10	10	60%	40%	0%	0%	100%
Q11	10	70%	30%	0%	0%	100%
Q12	10	50%	30%	20%	0%	100%
Q13	10	80%	20%	0%	0%	100%

Table 6.8: Likert Scale Results for VCUKL_GE technique

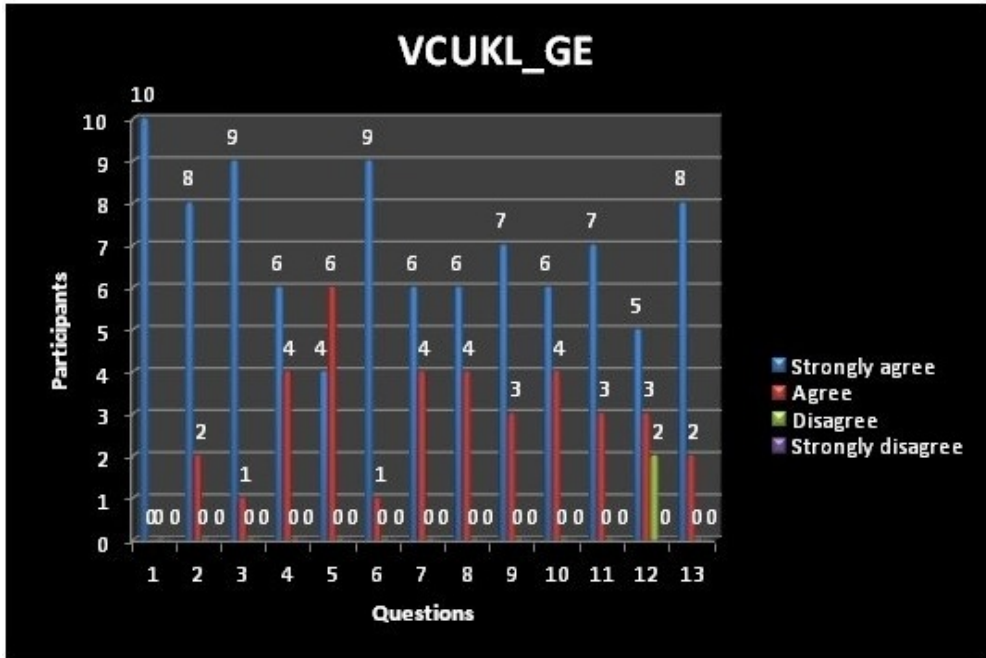


Figure 6.5: Chart of survey answers for VCUKL_GE .

6.5.4 Assessment of CiTIUS_Smart Board for Google Earth (CiTIUS_GE)

The results of the evaluation of the CiTIUS_GE method show a preference by users. CiTIUS_GE achieved the highest usability score. In addition, this technique scores well on structure and organization, and the users are satisfied with their accomplishment in performing their tasks (see Table 6.9).

Items	Achieved Average Rating		
	Expert	Inexpert	Total
Q1	4.0	4.0	4.0
Q2	3.8	3.8	3.8
Q3	4.0	3.4	3.7
Q4	4.0	3.4	3.7
Q5 B)	3.6	3.4	3.5
Q6 B)	4.0	3.6	3.8
Q7 B)	4.0	3.6	3.8
Q8	3.6	3.0	3.3
Q9	4.0	3.8	3.9
Q10	3.6	3.4	3.5
Q11	3.8	3.2	3.5
Q12	3.8	2.8	3.3
Q13	4.0	3.6	3.8
TOTAL	50.2	45.0	47.6

Percentage of 91.5

Table 6.9: Results of Usability survey for CiTIUS_GE

Table 6.10 shows the results from the point of view of the Likert scale; the result represents satisfaction for the criteria of usability. As we saw, this technique achieved 91.5 percent of the ease of use, and this percentage represents success for this method, making it a successful example to build on and use in different contexts and fields.

In addition, the users were satisfied with their accomplishment when performing their tasks. They were also satisfied with the amount of independent thought while using different functions and the active exercise of the map services. The results are illustrated once more in Figure 6.6.

Questions	Total	Strongly agree	Agree	Disagree	Strongly disagree	Total
Q1	10	100%	0%	0%	0%	100%
Q2	10	80%	20%	0%	0%	100%
Q3	10	70%	30%	0%	0%	100%
Q4	10	70%	30%	0%	0%	100%
Q5 B)	10	50%	50%	0%	0%	100%
Q6 B)	10	80%	20%	0%	0%	100%
Q7 B)	10	80%	20%	0%	0%	100%
Q8	10	30%	70%	0%	0%	100%
Q9	10	90%	10%	0%	0%	100%
Q10	10	50%	50%	0%	0%	100%
Q11	10	50%	50%	0%	0%	100%
Q12	10	50%	30%	20%	0%	100%
Q13	10	80%	20%	0%	0%	100%

Table 6.10: Likert Scale Results for CiTIUS_GE technique

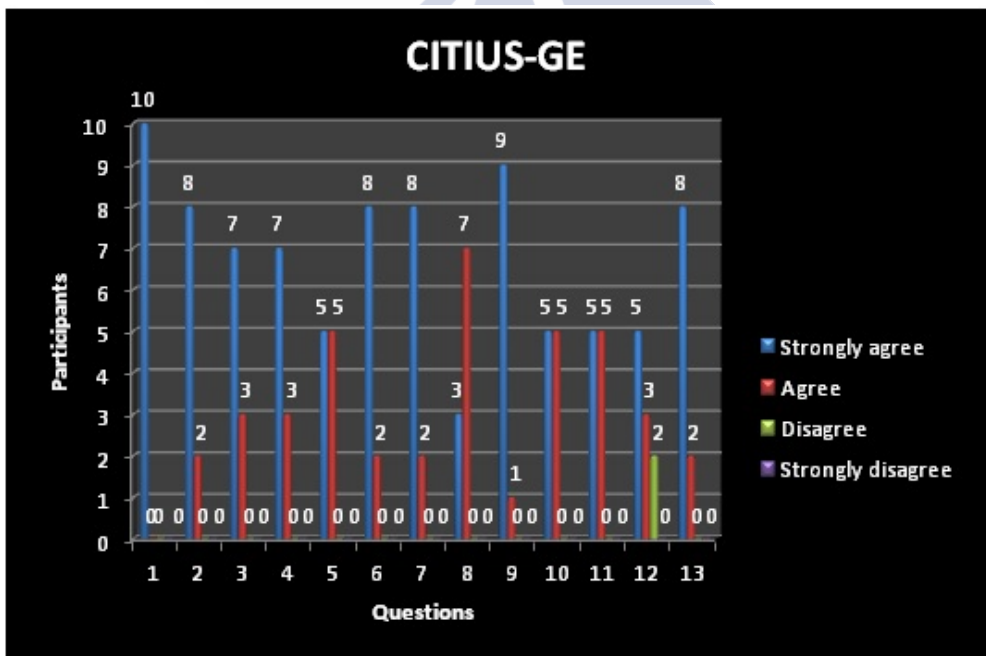


Figure 6.6: Chart of survey answers for CiTIUS_GE .

6.5.5 Assessment of CiTIUS Smart Board with Voice for Google Earth (CiTIUS _ SBV)

The final technique, CiTIUS_SBV, gained the confidence of users unanimously. Users agreed on its usability and reported that it has the best structure and organization. On the other hand, some of the users, especially non-experts, emphasize the need for help to manage the program, as we can see in Table 6.11, question 12.

Items	Achieved Average Rating		
	Expert	Inexpert	Total
Q1	4.0	4.0	4.0
Q2	4.0	4.0	4.0
Q3	3.8	4.0	3.9
Q4	4	3.6	3.8
Q5 B)	3.8	4.0	3.9
Q6 B)	4.0	4.0	4.0
Q7 B)	3.8	4.0	3.9
Q8	4.0	3.8	3.9
Q9	3.8	4.0	3.9
Q10	3.8	3.6	3.7
Q11	3.6	4.0	3.8
Q12	4.0	2.8	3.4
Q13	3.8	4.0	3.9
TOTAL	50.4	49.8	50.1

Percentage of 96.3

Table 6.11: Results of the Usability survey for CiTIUS _ SBV

Overall, we can say that this technique has been shown to be the most suitable method. This is evident clearly through the results of the application of the Likert scale as shown in Table 6.12 and Figure 6.7.

Questions	Total	Strongly agree	Agree	Disagree	Strongly disagree	Total
Q1	10	100%	0%	0%	0%	100%
Q2	10	100%	0%	0%	0%	100%
Q3	10	90%	10%	0%	0%	100%
Q4	10	80%	20%	0%	0%	100%
Q5 B)	10	90%	10%	0%	0%	100%
Q6 B)	10	100%	0%	0%	0%	100%
Q7 B)	10	80%	20%	0%	0%	100%
Q8	10	90%	10%	0%	0%	100%
Q9	10	90%	10%	0%	0%	100%
Q10	10	70%	30%	0%	0%	100%
Q11	10	80%	20%	0%	0%	100%
Q12	10	10%	40%	20%	0%	100%
Q13	10	90%	10%	0%	0%	100%

Table 6.12: Likert Scale Results for CiTIUS_SBV technique

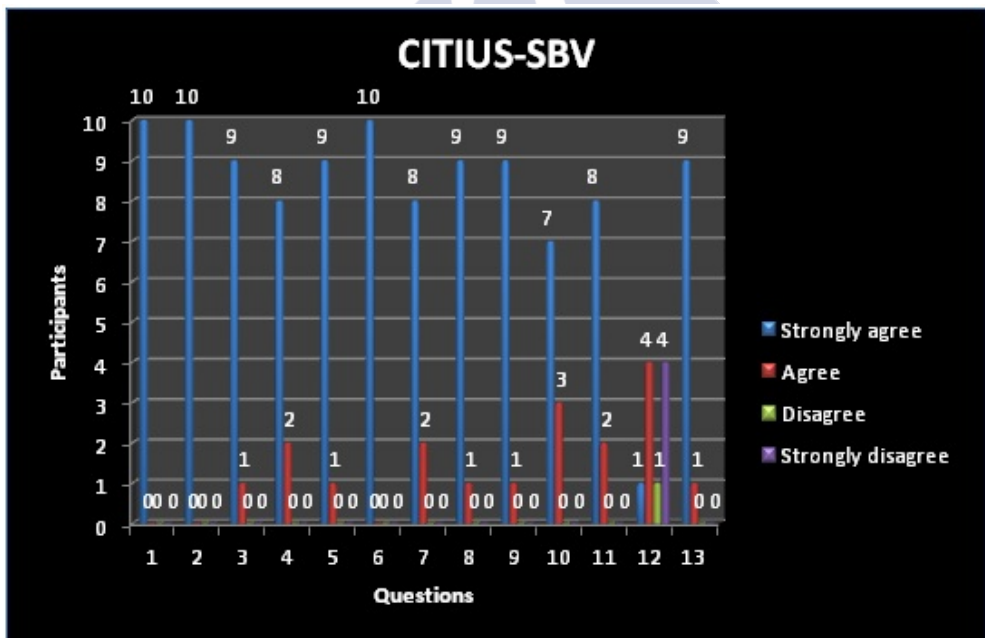


Figure 6.7: Chart of survey answers for CiTIUS_SBV .

In summary, the results of this survey indicate that the CiTIUS_GE method fulfills the users' needs. The analysis of the results of this survey show that CiTIUS_GE is a highly robust and versatile tool for usability professionals.

6.6 Conclusions of the Chapter

This chapter has presented the results of our usability survey for ArVS and discussed their implications. It is essential to be clear about what you want to evaluate and then design the instruments that best allow you to know what you want to know.

In this survey, we performed a quantitative and qualitative assessment of archeological sites data representation, to determine the usability of ArVS with efficiency and ease. The evaluation of ArVS is critical since the results we obtained will serve to guide developers in what they can do to enhance the overall system.

The evaluation process for the ArVS system was divided into two stages. First, we evaluated all of our visualization paradigms. Second, we tested each of our five HCI techniques.

From the results of the questionnaire about the visualization part of (ArVS), we conclude that we achieved the usability aims for which it was established. This will help guide the community in the production of high-quality visualization techniques in this field, and will add significantly to the evidence base necessary to promote successful commercialization, facilitate adoption by users and conduct future research tasks.

Based on the survey, the visualization in ArVS system may encourage researchers in the information visualization community to apply the proposed systematic approaches. This will contribute to the development and improvement of specialized tools and programs in geographic information systems, especially for archaeologists, to enhance their skills in exploration, using programs of high quality and feasibility which have low costs and high potential.

Furthermore, the achieved results achieved from these surveys can serve researchers for improving the usability of tools which are required to accomplish or enhance the accuracy of Human-Computer Interaction techniques. A summary of our results for these HCI techniques can be seen in Figure 6.8.

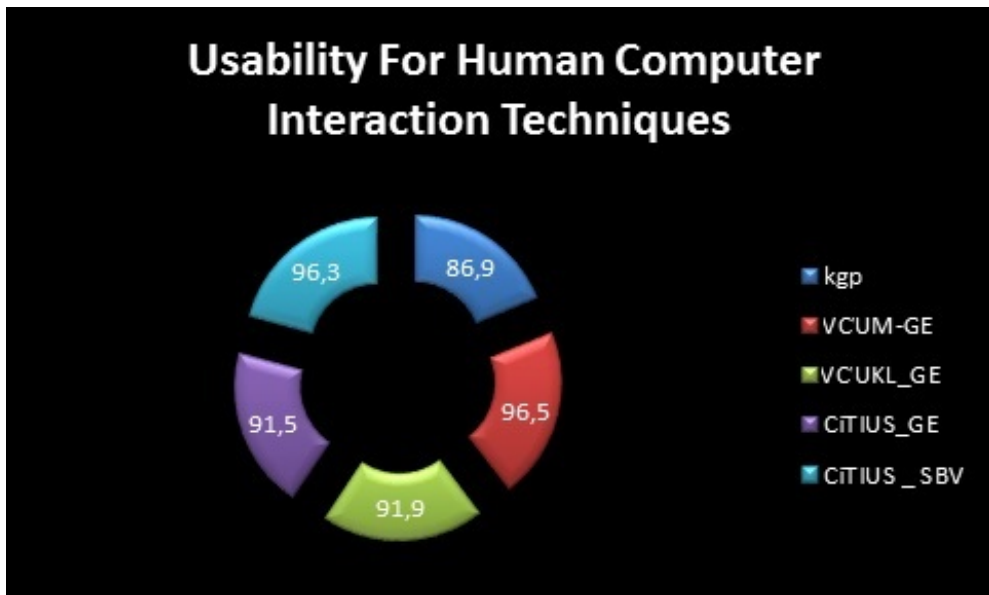


Figure 6.8: HCI Techniques Results .

In summary, the results exceed the eighty-five percent level for all paradigms and techniques, indicating that the goal of the ArVS system has been achieved within the standards of satisfaction of the user and the purpose for which it was established.

Finally, we can say that the whole system has contributed to the development of the field of information systems, especially geographical archeology.

CHAPTER 7

CONCLUSIONS AND FUTURE WORK

7.1 Discussion and Summary

This thesis has presented a research project related to Visualization and Interaction in GIS applications. Google Earth was used as an engine of GIS for visualizing different types of geodata. We have developed a software framework called the Scientific data Visualization System (SdVS) as a vehicle for our research. Further, for a specific case study we have developed the Archeological Visualization System (ArVS) and tested the visualization and interaction techniques with a set of scientific archeological data.

The integration of Virtual Geographical Environments in the ArVS was found to be very efficient as it could handle different kinds of data in 1, 2 or 3 dimensions, such as text, artifacts, and historic castles. Moreover, this system could provide access to the excavation database and efficiently update the visualization of it.

Our system involves the use of new visualization paradigms that could deal with data and represent objects at the same or very close spatial position. Besides, this system can provide an enhanced visualization of several layers without causing an overlap. The suggested subplacemark dialogue paradigm could reduce the time to fetch the desired information from the database, improving the performance of the suggested system. Our system can also adjust the data accuracy to fit with a specific Level of Detail (LOD).

In addition, the system incorporates the use of new techniques of human-computer interaction that could deal with maps and objects by navigation, this enables the system to help end-users to manage their GIS systems in general, and particularly to help archeologists, as those have tested our methodology with scientific excavation data, to explore their data and

analysis of excavations securely and handily with new methods for visualization and navigation.

Our system is scalable and straightforward in implementing, interacting with, and measuring a lot of other geodata. Some different functionalities are added. Because our system is dynamic.

Finally, according to the above, this thesis has tried to consider how to make navigation and data retrieval in GIS systems more comprehensible and accessible to the general public. The integration of new visualization and interaction techniques facilitates better understanding of archeological information even by non-expert users.

7.2 Conclusions

We believe that the different objectives of this research have been successfully achieved. We can draw the following conclusions:

1. A distributed and scalable architecture has been designed, implemented and tested, that allows operating with low-cost devices and open software in GIS interaction systems.
2. Five different forms of interaction techniques have been implemented and tested.
3. Six new visualization paradigms have been developed and implemented, enabling users to visualize and interact with their data and to obtain knowledge in an attractive and different way.

Multimodal interaction as developed in the ArVS system has a lot of potential uses in GIS applications, because it is a natural way to communicate with the computer. This kind of interaction favors the experienced user in this field. In particular, the combination of gestures and voice has shown that they complement each other to define actions of Navigation in 2D / 3D visual applications.

We have developed a new software component that integrates several devices, including Kinect for gesture recognition, microphones for voice recognition, and a large display device. This component was integrated into a functional prototype that uses multimodal interaction based on voice and hand gestures for navigation on 2D and 3D maps using any GIS software. It was tested using Google Earth.

After carrying out an initial study with users, we have concluded that the system with multimodal interaction generates a lot of interest and expectation from the users and the user

experience is affected by the quality and performance in recognition of gestures and voice commands.

The use of the 3-D Historical Buildings shown inside virtual environments such as Google Earth can help to visualize the artifacts represented in the scene. This research project could be useful nowadays to protect and preserve Heritage and Archeological Data at all countries suffering from the destruction of structured archeology and information, due to terrorism and wars.

7.3 Future Work

In general, changes in the technological environment of GIS will open a set of challenges that create the need for continuous enhancement and assessment of the SdVS system.

In the field of human-computer interaction in virtual geographic information platforms, the system can be expanded to use new architectures, low-cost sensors and different devices. The SdVS can be applied to different domains according to the desired requirements.

Results achieved allowed defining the directions of future work, in two senses: how to improve our system and how to extend its use to other domains.

We can consider the following ideas to improve our system:

- A future release of SdVS could consider working with mobile/tablet devices.
- We will optimize the data storage for efficient recovery of data, and for a continuous visualization with new paradigms.
- Improve the efficiency of the recognition modules by increasing the recognition rate of gestures and voice commands and / or decreasing the response time measured from the actions given by the user. These improvements seek to increase usability and user satisfaction when interacting with a 2D / 3D visual application through the use of the multimodal interface.
- Provide a mechanism for learning new gestures and new voice commands, seeking to favor extensibility and performance of the recognition component.
- Test the multimodal interaction component with other 2D / 3D visual computing applications. Initially, applications in visualization/analysis of images for medical diagno-

sis, video games and/or teleoperation of mobile robots in risky environments have been identified as potential new domains.

- Improve the interaction space taking into account:
 - * Activation Mode: Start the interaction with the user with a Start gesture (e.g., gesture greeting/wave). This is to make sure that other people may be in the environment without intervening in the interaction.
 - * Deactivation Mode: Temporarily interrupt the interaction with the user so other activities can be carried out, or if the user is not in a position to be detected correctly.
 - * Identify the address from which the voice commands come to receive only commands from the active user.

We could expand our research also in the following ways:

- We could research in the new human-computer interaction fields, for example, incorporating Brain-Computer interface techniques (BCI) by using Brainwave Starter Kit. This would enable the users to use any graphics engine in a non-conventional way; therefore, they can employ all these things with geovisual storytelling and the education framework.
- Improve the interoperability of the system, integrating new standards for interoperability such as web services proposed by OGC. This would allow the integration of new archeological databases [43, 160, 161].
- Integration and improvement of 3D buildings as scenarios, which can allow navigation inside a 3D real environment and representation of georeferenced objects inside. Some problems to be solved could include how to make a difference between gesture orders, and natural movement inside the 3D scenario.
- Integrate Artificial Intelligence with Gesture Recognition to avoid errors in the interpretation of natural gestures and voice.
- Integrate of special devices for disabled persons. These devices will provide an opportunity for these people to interact with geodata information such as tourism information, which enables them to communicate with the tourist and archeological sites.

- Finally, an interesting research line would be how to apply advanced interaction techniques in virtual television [162, 163].





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ACRONYMS AND ABBREVIATIONS



Acronyms	Concepts
ArVS	Archaeological visualization System
AVA	Archeological Visual Analytics
BSI	Base Surface Imagery
CESGA	Technological Center of Supercomputing of Galicia / Centro Tecnológico de Supercomputación de Galicia
CGP	Control – GIS – Primary
CiTIUS _ SBV	CiTIUS Smart Board with Voice for GIS Applications
CiTIUS	The Research Center in Information Technologies / Centro de Investigación Singular en Tecnologías de la Información
CiTIUS_GIS	CiTIUS_Smart Board for GIS Applications
DEM	Digital Elevation Model
EROS	The Center of Earth Resources Observation and Science
GE	Google Earth
GIS	Geographic nformation System
GIScience	Geographic Information Science
GPS	Global Positioning System
GSV	Google Street View
HCI	Human Computer Interaction
JRGC	Jordanian Royal Geographical Center
KML	Keyhole Markup Language
NUI	Natural User Interface
OGC	Open Geospatial Consortium
PCT	Parallel Coordinate Technique
SDI	Spatial Data Infrastructure
SdVS	Science Geo-data Visualization System
SPI	Service Provider Interfaces
STC	Space Time Cube
SUS	System Usability Scale
VA	Visual Analytics
WMS	Web-Map Service